Ads

GEORGIA INSTITUTE OF TECHNOLOGY
OFFICE OF CONTRACT ADMINISTRATION
SPONSORED PROJECT INITIATION

Date: July 7, 1977

Project Title: Effect of Infrared Radiation on Compaction of Municipal Wastewater Sludges

Project No: B-491

Project Director: Dr. Stephen C. Havlicek

Sponsor: National Science Foundation (NSF/RANN)

Agreement Period: From 7/1/77 Until 12/31/78
(12-month budget period plus 6-month flexibility period)

Type Agreement: Grant No. ENV77-15086

Amount: $21,900 NSF
1,121 GIT (E-)
$23,021

Reports Required: Interim Progress Reports; Final Technical Report; Summary of Completed Project Report

Sponsor Contact Person (s):

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Defense Priority Rating: N/A

Assigned to: Applied Sciences Laboratory (School/Laboratory)

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CA-3 (3/76)

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OFFICE OF CONTRACT ADMINISTRATION

SPONSORED PROJECT TERMINATION

Date: 2/10/79

Project Title: Effect of Infrared Radiation on Compaction of Municipal Wastewater Sludges

Project No: B-491

Project Director: Dr. Stephen C. Havlicek

Sponsor: National Science Foundation (NSF/RANN)

Effective Termination Date: 1/31/79

Clearance of Accounting Charges: 3/31/79

Grant/Contract Closeout Actions Remaining:

- X Final Invoice and Closing Documents
- X Final Fiscal Report
- _ Final Report of Inventions
- _ Govt. Property Inventory & Related Certificate
- _ Classified Material Certificate
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Assigned to: Technology & Development (School/Laboratory)

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CA-4 (3/76)

B-491

ENGINEERING EXPERIMENT STATION
GEORGIA INSTITUTE OF TECHNOLOGY • ATLANTA, GEORGIA 30332

December 20, 1977

Dr. Edward H. Bryan
Program Manager
Advanced Environmental Research
National Science Foundation
Washington, D.C. 20550

Dear Ed:

Enclosed please find an interim report on your Grant # ENV 77-15086

The data would indicate that lignosulfonate is the cause of both the increase in and reduction of sludge volume. Thus, one has to cause bulking to cure it! I suspect that Phase I has produced enough information to make the second phase unnecessary. We will hope to get some very positive support for our conclusions within the next few weeks.

May I say that I sincerely appreciate, as a scientist, having been able to study such an interesting phenomenon which had a glimmer of useful application.

Please accept my best wishes for the holiday season and a Happy New Year!

Sincerely yours,

Robert S. Ingols
Consultant on the Project

for

Stephen C. Havlicek
Principal Investigator

RSI/mam
Enclosure

EFFECT OF INFRARED RADIATION ON COMPACTION OF MUNICIPAL WASTEWATER SLUDGES

Progress Report

December 21, 1977

by

Dr. R. S. Ingols

Dr. S. C. Havlicek*

Mr. M. Poythress

Georgia Institute of Technology
Atlanta, Georgia 30332

NSF Grant Number ENV 77-15086

Dr. Edward H. Bryan
Program Manager
Advanced Environmental Research
National Science Foundation
Washington, D.C. 20550

* Principal Investigator to whom inquires should be directed.

EFFECT OF INFRARED RADIATION ON COMPACTION OF

MUNICIPAL WASTEWATER SLUDGES

by

Ingols, Havlicek, and Poythress

Following the award of the research grant, the three-compartment pilot plant (outlined in the proposal) for studying compaction of the bulky activated sludge at Macon (Georgia) was installed. After installation, a few observations were possible but modifications of the paper mill processes brought wastewater changes which made procedures in the proposed program of study inappropriate. In October, there was no bulking at the Rocky Creek Wastewater Treatment Plant and no evidence of a compaction phenomenon as the new pilot plant began operating.

In order to understand how the observations at the Macon facility gave an indirect comprehension of the phenomenon without using results from our new pilot plant, a review of the factors controlling the quality of the paper mill discharge is considered important.

A plastic membrane trickling filter was placed in operation by the paper mill very soon after starting up the original pilot plant (1969) to treat the process water from steam ejector cooling for reuse. The counter-current forced draft on the plastic film filters provided for evaporative cooling of the heated water while the filter surfaces provided for slime growth to reduce the BOD of the sugars in the recycled water. Anticipated flow to the full scale plant was reduced from 60,000 m^3/d to 30,000 m^3/d while also reducing the anticipated BOD load.

Recently, the paper mill has increased its water reuse and reduced the flow by another 50% to 15,000 m^3/d while reducing the BOD concentration by almost 50% from the average of the higher flow.

Twice within the last few months of 1977, sensitivity to infrared with sludge compaction has disappeared. The first time, supernatant from the waste sludge lagoon was added to the raw sewage input. The lignosulfonate color had been altered. It was believed that the sulfonate had been altered - reduced - to the valence of sulfur corresponding to a sulfhydryl group. This observation was made while trying to answer a reviewer's comments after submitting the proposal. The black sludge gave no shrinkage in direct sunlight. (There was a strong sulfide odor from the lagoon and aeration tank.) It is possible that other less obvious changes may also have occurred; these changes would have included deamination of the glucosamine polymer which was also present in the sludge lagoon.

Recently, a reduction in the flow was accomplished by recirculation of another process water within the mill. The recirculation brought a marked reduction both of the lignosulfonate color of the floc and the sludge index (SI). When the loss of bulking occurred, the sludge failed to compact. After several weeks of this condition, the mill began pumping down an old lagoon. The water from this lagoon had a low BOD from destruction of the sugars but had retained a high and normal lignin color, because the because the anaerobic conditions lagoon had not been destructive of the lignosulfonate. With the return of lignin color, the SI increased in the wastewater treatment plant from 200 to 300 and the sludge compaction phenomenon returned.

It would appear that lignosulfonate is needed both to cause the sludge bulking (to develop a high SI) and to bring about the compaction response to IR.

Two other causes have been considered as explanations:

(1) It was observed in the experimental units at Macon that the infrared rays of the sun do cause an increase in temperature in the industrial wastewater over the compartments with domestic wastewater. Thus, it is interesting to know whether the increase in temperature is the true cause of the sludge compacting. When a cylinder of sludge which responds is placed in an oven, no compaction occurs. When the sludge is removed from the oven and exposed to sunlight (IR) it does compact. If the sample is first chilled in a refrigerator and then exposed to IR, the shrinking phenomenon occurs in the chilled sludge. Thus, it is concluded that though temperature changes occur with IR, it is not the temperature change per se which causes compaction.

(2) Paper mill wastewater with little or no preliminary treatment contains lignosulfonates and degradation products of cellulose (cellulose, smaller polymers, cellobiose, glucose). Because the senior author of this report was aware that sugar can induce bulking, the assumption was made that sugars in the paper mill wastewater induced the bulking condition observed at the 1969 pilot plant. When 600 mg/l of table sugar was added to a compartment in the new experimental set-up at Macon, bulking did develop on a temporary basis, but no compacting phenomenon accompanied the bulking by the sugar because at that time there was very little lignosulfonate in the paper mill wastewater. Thus, it is concluded that common causes of bulking would not be aided by the compaction phenomenon from lignosulfonate.

Agitation of a sample reverses the compaction while IR will initiate the compaction several times sequentially. This reversable reaction indicates to the authors that the phenomenon results from the formation of an easily disrupted chemical bond - possibly a weak hydrogen bond or an electrostatic attraction initiated by the IR. The hypothesis would require an intimate mixture of the glucosamine polymer of the Zooglea ramigera floc and lignin. Thus, when agitation by IR photons occurs, each polymer may be ionized to form a salt bridge or hydrogen bonding may develop. (The amine of glucoamines may ionize along with the sulfonic or phenol radicals of the lignosulfonate.) These reactions do not occur simply by mixing lignosulfonate with the normal activated sludge floc; several days are required for the development of the intimate mixture of the two polymers so that the bulky mixture can produce a large difference in the SI's between light and dark. The expansion of the floc by the lignin makes the overall idea of using the phenomenon as a practical treatment device quite undesirable though still interesting.

While it appears that we do understand what causes the bulking and compaction, we have not developed each factor under experimental conditions. A 110 liter barrel has been fitted for direct observation of modified domestic wastewater treatment with activated sludge along with a solution of commercial lignosulfonate. This will be done at an Atlanta treatment plant during the first part of 1978.

B-491

ENGINEERING EXPERIMENT STATION
GEORGIA INSTITUTE OF TECHNOLOGY • ATLANTA, GEORGIA 30332

August 3, 1978

Dr. Edward H. Bryan
Program Manager
National Science Foundation
Division of Problem-Focused
Research Applications (PFRA)
1800 G Street, N.W.
Washington, D.C. 20550

Subject: Interim Progress Report
"Effect of Infared Radiation on Compaction of Municipal Wastewater Sludges"
Grant No. ENV77-15086
Georgia Tech Project No. B-0491-000

Dear Dr. Bryan:

Enclosed are copies of our interim progress report. I have deliberately tried to put this report in the correct format for final progress reports. I would therefore appreciate your comments regarding possible format errors. The final report should be ready in a few months so that we can close out the project on time.

Sincerely,

Stephen C. Havlicek, Ph.D.

SCH/mam
Enclosures

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PROGRESS REPORT: JANUARY - JUNE 1978

EES/GIT PROJECT B-491

EFFECT OF INFRARED RADIATION ON COMPACTION OF MUNICIPAL WASTEWATER SLUDGES

NSF GRANT ENV 77-15086

DR. R. S. INGOLS AND DR. S. C. HAVLICEK
AND MR. M. H. POYTHRESS

JUNE 1978

ENGINEERING EXPERIMENT STATION
GEORGIA INSTITUTE OF TECHNOLOGY
ATLANTA, GEORGIA 30332

DISCLAIMER

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CREDIT LINE

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Progress Report: January - June 1978

EES/GIT Project B-491

EFFECT OF INFRARED RADIATION ON COMPACTION OF MUNICIPAL WASTEWATER SLUDGES

NSF Grant ENV 77-15086

Dr. R. S. Ingols and Dr. S. C. Havlicek
and Mr. M. H. Poythress

June 1978

ENGINEERING EXPERIMENT STATION
Georgia Institute of Technology
Atlanta, Georgia 30332

EXECUTIVE SUMMARY

The activated sludge process is widely employed for the treatment of wastewaters from both domestic, industrial and mixed sources. The success of this treatment is dependent upon the separation of solids in the secondary sedimentation tank and upon their concentration for subsequent return to the aeration tank. Therefore it is not surprising that bulking (poorly settling) sludges exacerbate difficult disposal problems which are already one of the major headaches associated with wastewater treatment. It would thus seem worthwhile to explore any process which had the possibility of reducing the extra load of waste sludge caused by bulking conditions or which could bring about compaction of wastewater sludges in general. New methods of sludge debulking which do not involve the use of chlorine are particularly interesting since it has already been established that this practice, while effective, leads to the production of potentially hazardous chloroorganic materials.

Since the authors had noted the occurrence of an unusual infrared-induced sludge compaction phenomenon which took place at Macon, Georgia's Rocky Creek wastewater treatment facility, a research program was proposed to and subsequently funded by the National Science Foundation to investigate the nature of the phenomenon in the hope that a method for making the IR-enhanced settling generally applicable could be demonstrated.

The compaction phenomenon is quite dramatic as can be seen by comparing the photographs of treated and untreated sludge as shown in

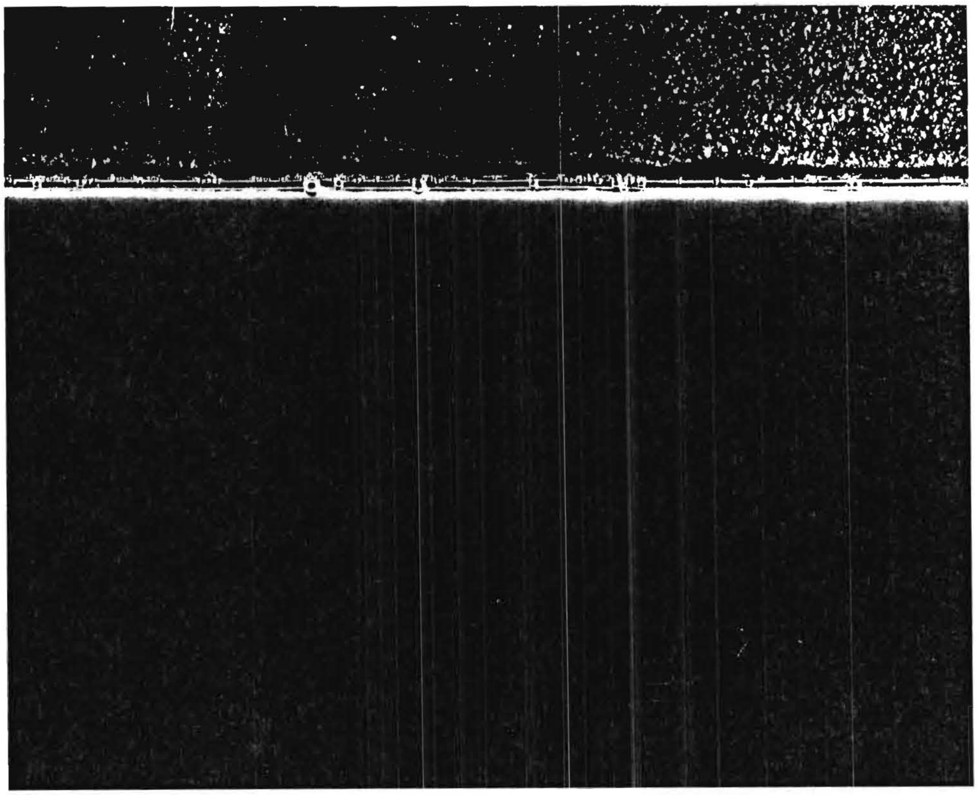
Figure 1. It was first observed at Macon during the pilot studies which preceded the construction of the Rocky Creek treatment facility. It is believed to be a characteristic of the mixed domestic and pulp-mill wastewaters which are processed by this plant. It was hoped that some active ingredient in the mixture was responsible for inducing the phenomenon and could be economically isolated and/or concentrated for general use.

A number of general tests have been run to better describe the phenomenon and thereby gain additional information regarding its probable mechanism and/or its general utility. Thus far, none of these tests have suggest that a practical application for the phenomenon will be found. In fact, evidence gathered in recent months suggests that either;

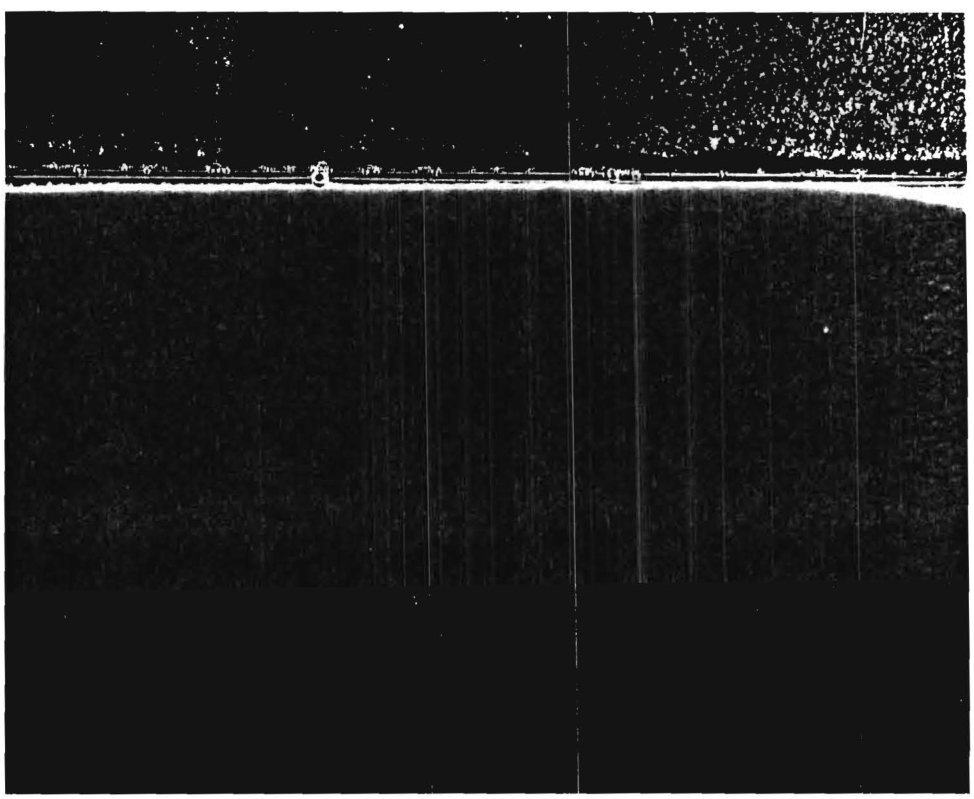
1) Conditions have changed at Macon so that the true IR-induced compaction is now observed only infrequently
2) Transporting the sludge to Atlanta requires that the containers be sealed for approximately six hours during which time the phenomenon is irreversibly destroyed
3) Original observations at Macon which dismissed the heat effect were incorrect

All of the Phase I tasks have been completed.

A three-compartment mini-pilot facility was constructed and placed in operation at the Rocky Creek (Macon) wastewater treatment facility and operated with various proportions of domestic and pulp-mill waste in an effort to determine what was the minimum pulp-mill contribution required to produce a response to infrared radiation. Although this series of experiments was complicated by changes in the water reuse patterns within the pulp-mill which prevented the assignment of a minimum value, this work provided the first evidence that the pulp-mill waste stream was producing the bulking phenomenon as well as

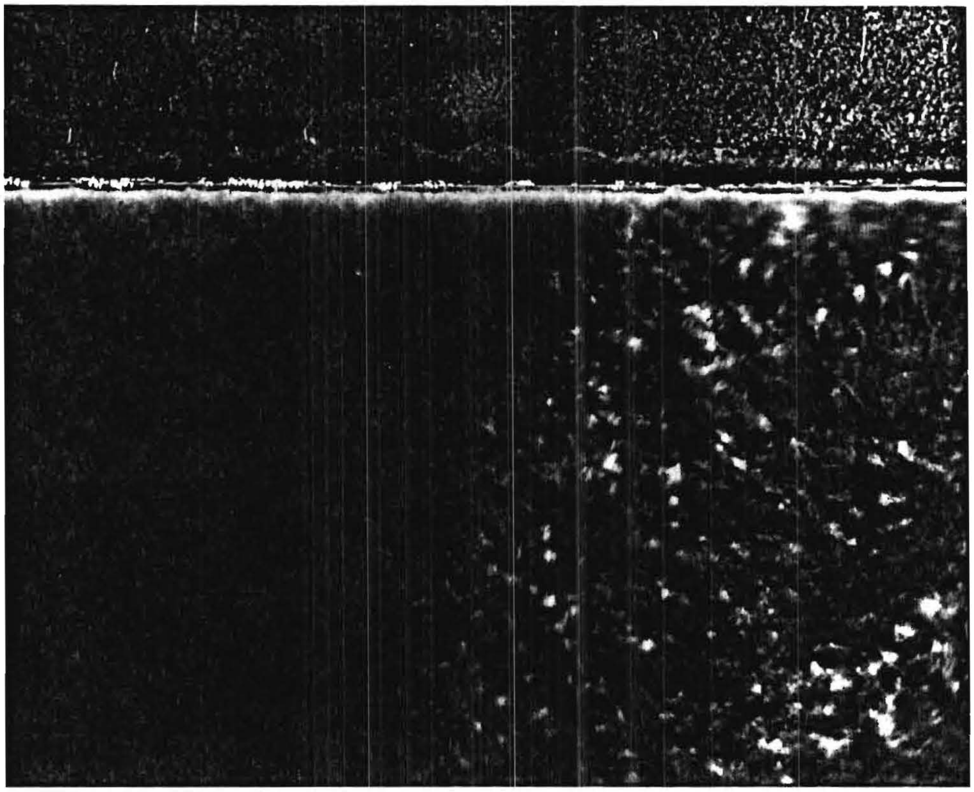


0 minutes

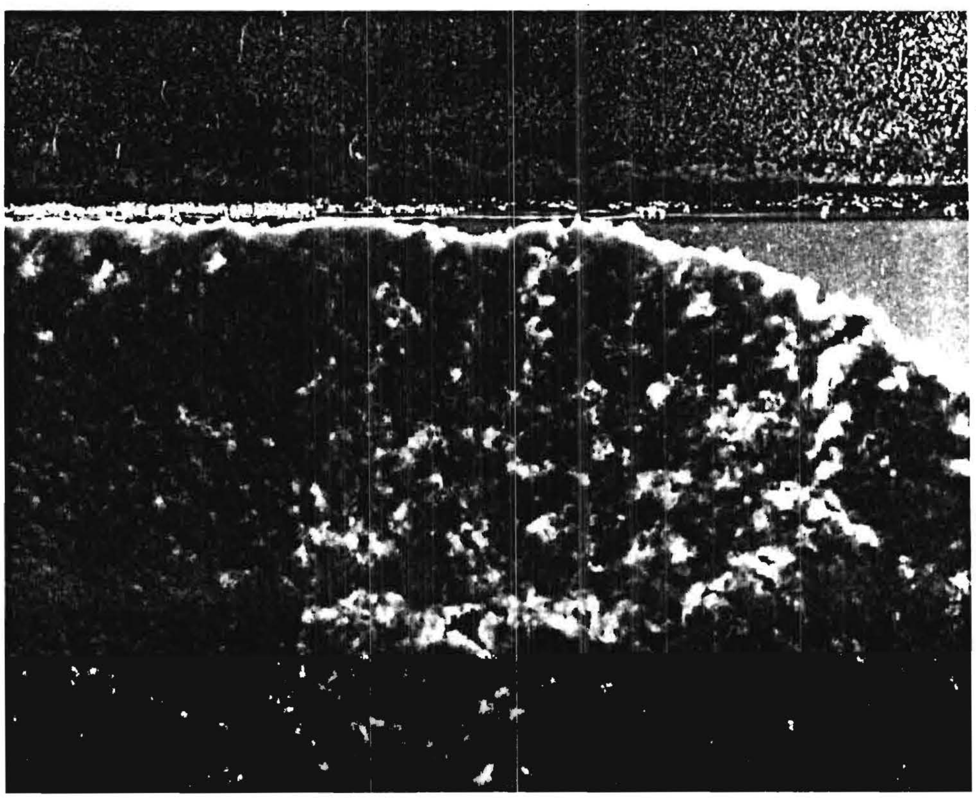


2 minutes

Figure 1a. IR-Induced Settling as a Function of Time

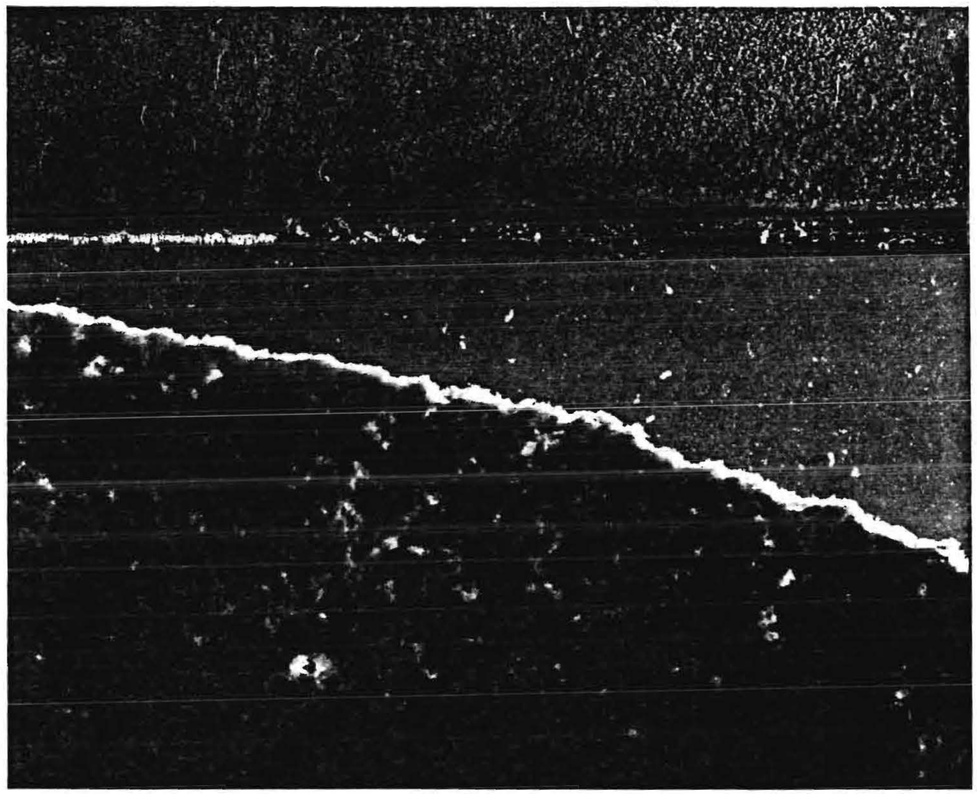


4 minutes



6 minutes

Figure 1b. IR-Induced Settling as a Function of Time



8 minutes

Figure 1c. IR-Induced Settling as a Function of Time providing a means for the cure. Bench testing was generally supportive of these observations leading the writers to evaluate the phenomenon as being unlikely to have practical utility. Accordingly it was recommended that Phase II not be funded. The remainder of this report describes the results of key experiments, the conclusions to be drawn from the experimental evidence and the recommendations for future research activity in this area.

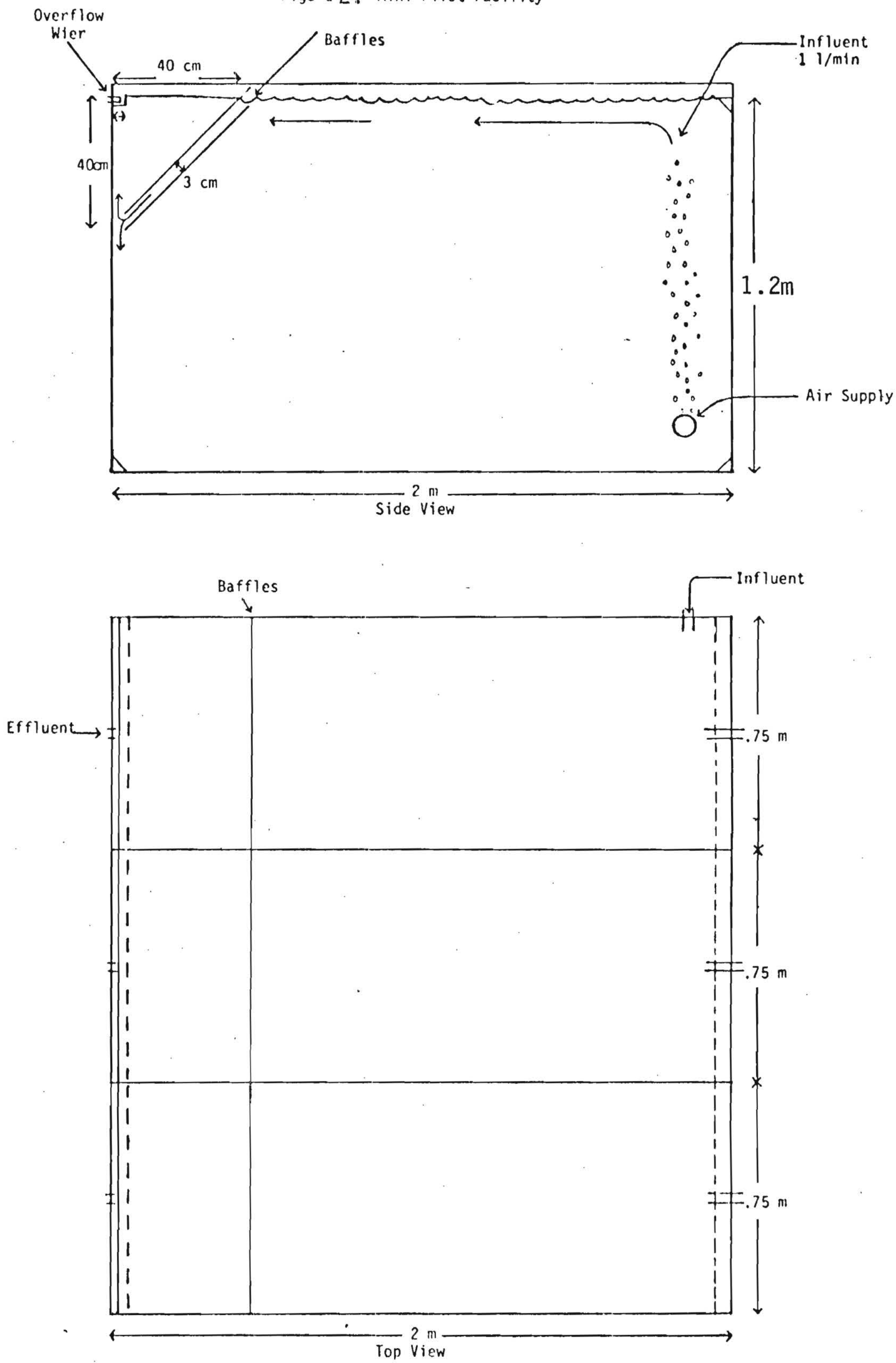
DESIGN OF IRRADIATION EXPERIMENTS

Early experiments were conducted using a commercial infrared lamp placed approximately 50 cm away from a 500 or 100 ml graduated cylinder containing freshly agitated sludge. A control cylinder was agitated and allowed to stand in a dark corner for the same length of time. Some of the more recent experiments have employed a 100 ml graduated cylinder placed on a phonograph turntable a specified distance from the light source. In this way unequal convection currents would not be set up along the side of the cylinder nearest the lamp. It was first believed that this precaution would only be important for cases in which the test cylinders were so close to the lamp (within 20 cm) that significant heating would occur. Actual temperature readings are now recorded even when the cylinders are 1.0 or 1.5 meters away from the light source as we have become more aware that heating effects are playing a major role in the compaction phenomenon as it is now being observed in the laboratory.

CONSTRUCTION AND OPERATION OF THE MINI-PILOT FACILITY

A three-compartment pilot facility was constructed at Georgia Tech immediately following the award of the contract. The design of this apparatus is shown in Figure 2 and is essentially as outlined in our original proposal. The volume of each compartment was about 1.6 m^3. The general rate of feeding was about 1 l/min. The pulp-mill wastewater stream and the domestic wastewater stream were mixed in varying proportions in an effort to determine the minimum pulp-mill contribution required to have the sludge respond to irradiation. These experiments were confused somewhat by irregularities in the composition of the pulp-mill waste stream as the test period coincided with the institution of new water recycling procedures within the pulp-mill itself. Thus the results were somewhat inconclusive. Within the next few weeks, we plan to reexamine this data and will summarize any new evidence thus obtained in our final report.

Figure 2. Mini-Pilot Facility



SETTLING PROFILES

Prior to becoming aware of the possible significance of heat alone as a contributor to the compaction phenomenon, the authors had run a number of experiments designed to obtain a profile of the IR-induced settling phenomenon as compared with setting in the absence of irradiation. A graphical representation of some typical results is presented in Figure 3. Each point on the two uppermost traces is the average from at least three separate runs. Dr. Ingols tells me the pre-award curves were more like the lowest trace.

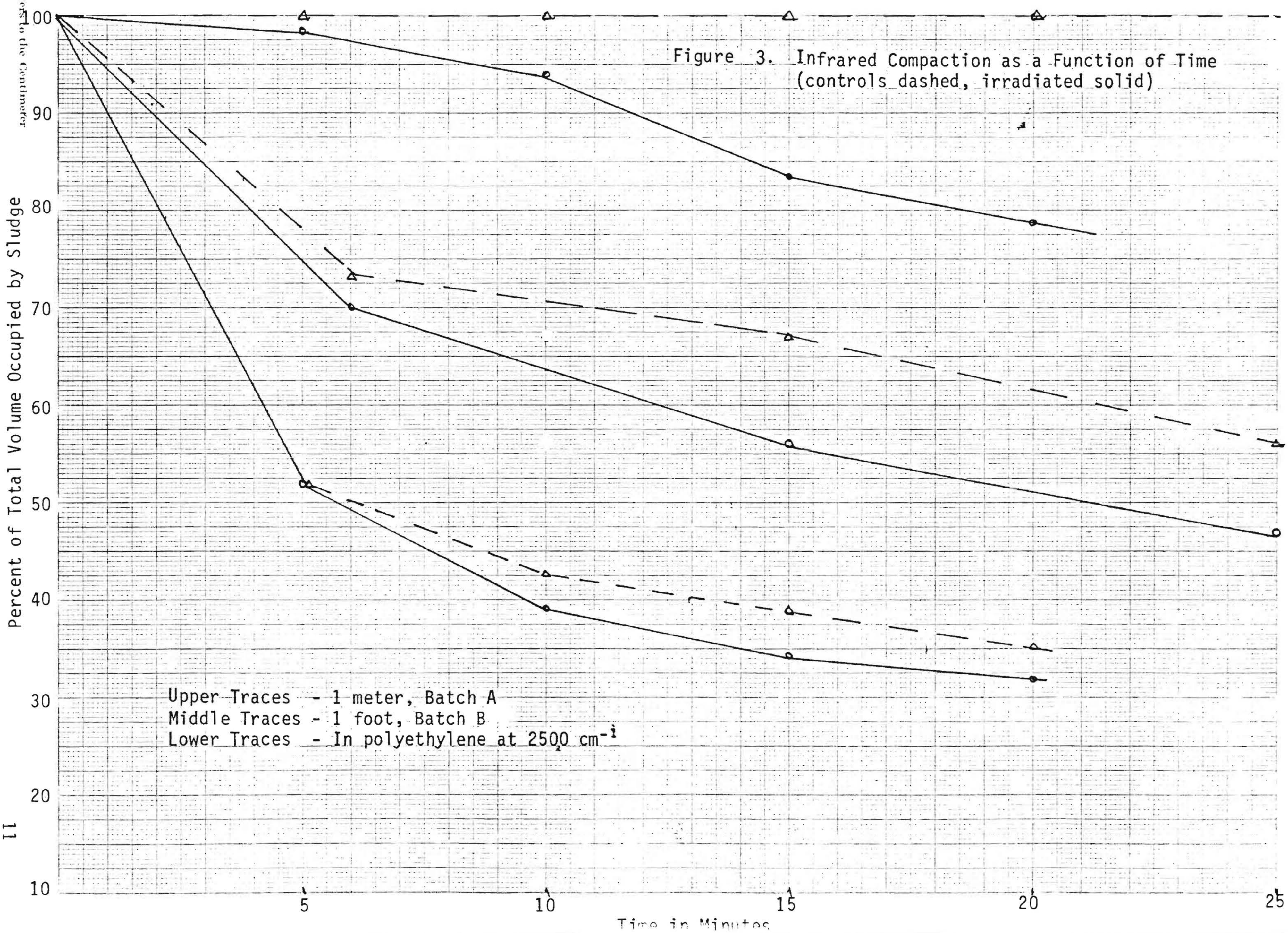


Figure 3. Infrared Compaction as a Function of Time (controls dashed, irradiated solid)

BENCH STUDY - FILTERABILITY

This experiment was designed to determine whether or not differences in the filtration rates could be observed between irradiated sludge and sludge which had not been exposed to infrared radiation. A Buchner funnel was mounted on a filter flask which was, in turn, connected to a constant vacuum source. A disc of Watman No. 1 filter paper was moistened and placed in the funnel for each test. Precision was established by observing the time required to filter 450 ml of tap water. These results are outlined below.

Run	Time in Sec.
1	40
2	40
3	47
4	39
5	50
6	48
7	47
Mean	44.4
Standard Deviation	4.6
% Standard Deviation	±10

This degree of reproducibility was considered to be acceptable. Accordingly 450 ml portions of sludge were filtered. The times required to bring the visible film of water away from all but the outer ring of the filter cakes were recorded for both control and irradiated sludge as outlined on the next page.

Run	Control	Irradiated
1	13.2	17.2
2	14.2	13.2
3	12.5	11.5
4		17.5
Mean	13.3	14.9
Standard Deviation	0.85	3.0
% Standard Deviation	±6.4	±20.0

t = 0.89 for 5 degrees of freedom

Because the two means were not significantly different and because the temperatures of the irradiated sludges had not been controlled, a more rigorous experiment was devised in which the effects of both temperature and irradiation were considered. Measurements were made on the same day using the same batch of sludge (Macon, GA). A factorial design was employed with two levels in each factor being considered as shown below along with the times required for filtration in minutes.

Factor 1 Lamp Irradiation		Factor 2 Temperature	
Level 1 On	Level 2 Off	Level 1 22°C	Level 2 38°C
4.75	4.37	4.0	5.5
6.15	6.0	4.5	3.68
5.5	5.17	4.0	5.2
5.25	4.7	4.82	4.0
5.17	4.87		

These results were subjected to statistical analysis on Georgia Tech's CYBER 74 time-shared computer system using the SPSS ANOVA n-way

analysis of variance program. The results of this statistical treatment of the data, which are presented below show that no statistically significant effect of the irradiation alone was observed. On the other hand, a significant temperature effect (p = 0.027) was noted. The two-way interaction was not significant. The temperature effect is to be expected on theoretical grounds and therefore supports the overall validity of the experiment.

\- - - ANOVA - - -

TIME
BY LAMP
TEMP

SOURCE OF VARIATION	SUM OF SQUARES	DF	MEAN SQUARE	F	SIGNIF OF F
MAIN EFFECTS	2.395	2	1.198	3.Ø72	.Ø78
LAMP	.Ø23	1	.Ø23	.Ø6Ø	.81Ø
TEMP	2.372	1	2.372	6.Ø84	.Ø27
2-WAY INTERACTIONS	.4Ø9	1	.4Ø9	1.Ø5Ø	.323
LAMP TEMP	.4Ø9	1	.4Ø9	1.Ø5Ø	.323
EXPLAINED	2.8Ø5	3	.935	2.398	.112
RESIDUAL	5.457	14	.39Ø		
TOTAL	8.262	17	.486		

18 CASES
Ø MISSING (Ø PCT)

The t-test data which are presented below include the means, standard deviations and standard errors for each of the cells. These results also support the conclusion that irradiation produced no significant changes while the elevated temperature produced a significant improvement in the filtration rate.

\- - - T - TEST - - -

TIME

	GROUP 1 Lamp On	GROUP 2 Lamp Off	
NO. OF CASES	9	9	
MEAN	4.9044	4.8322	
STD. DEV.	.7006	.7341	
STD. ERROR	.2335	.2447	
F-VALUE	1.10		
2-TAIL PROB.	.898		

	T-VALUE	DF	P-VALUE
POOLED VAR. EST.	.21	16	.834
SEPARATE VAR. EST.	.21	15.97	.834

\- - - T - TEST - - -

TIME

	GROUP 1 22^oC	GROUP 2 38^oC
NO. OF CASES	10	8
MEAN	5.1930	4.4625
STD. DEV.	.5663	.6550
STD. ERROR	.1791	.2316
F-VALUE	1.34	
2-TAIL PROB.	.669	

	T-VALUE	DF	P-VALUE
POOLED VAR. EST.	2.54	16	.022
SEPARATE VAR. EST.	2.50	13.99	.026

MEMORY EFFECT

If the infrared-induced compaction involves a redistribution of surface charges as has been speculated in earlier reports, it would seem unlikely that such an effect would be totally reversible. While early results had indicated that a very high degree of reversibility was characteristic of the phenomenon, a quantitative assessment of this observation was not undertaken until the current reporting period. A sample of sludge from the Macon facility was placed in a 100 ml graduate and subjected to infrared radiation in the usual manner. After 10 minutes of irradiation, the ratio of percent settling in the control to that of the irradiated sample was 2.9. The two samples were then resuspended and allowed to resettle. The ratio recorded after 4 minutes was 1.4 thus demonstrating that the effect is only partly reversible.

SETTLING VS. WAVELENFTH

Preliminary tests designed to uncover a dependency of the compaction phenomenon upon the wavelength of the incident radiation were carried out in quartz UV - vis spectrophotometer cells. Unfortunately, these cells were transparent (80% T or better) only from 2800-3400 cm^{-1}. Some light was able to pass through the cells from 2100-3800 cm^{-1} (10% T or better), albeit with varying intensity. For this reason, nearly all of the observations made with this equipment must be regarded as inconclusive. The results described in our letter of April 19, 1978 are worthy of note, however, since the ratios of control to irradiated samples were found to be 1.3 at 2100 cm^{-1} and 2200 cm^{-1} and nearly unity at 2300, 2400 and 2700 cm^{-1} in spite of the fact that the cells are more transparent to infrared radiation at those wavelengths. Unfortunately, this difference, although still observed in subsequent repeated experiments was not nearly as dramatic and, in fact, was no longer sufficiently large to be considered statistically significant.

In an effort to overcome this difficulty, new cells were constructed first out of polystyrene and finally out of polyethylene. While both were found to have vastly improved transmission properties when compared to those exhibited by the quartz cells, the polyethylene showed only three narrow adsorption bands at 2900-3150, 1480-1530 and 760-780 cm^{-1} and was essentially transparent throughout the rest of the range of the spectrophotometer. Since polystyrene had a number of other bands in addition to these three, all subsequent work has been carried out with the polyethylene.

While experiments in this area still need some wrapping up, irradiation for 15-20 minutes shows an effect at 2200 and 2300 cm^{-1} but not at 2500 cm^{-1}. The observed ratios of control to irradiated samples were 1.2, 1.1 and 1.0 respectively. This evidence agrees with that reported earlier. Temperatures were not recorded.

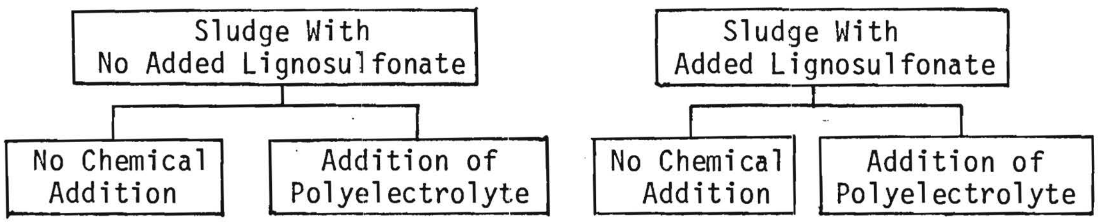
EFFECT OF pH, SALT, DETERGENT AND SOLVENT EXTRACTION

Changing the pH to 4 and 9 did not alter the degree of response to infrared radiation. Adding a sufficient amount of sodium chloride to make the resulting mixture 1% in NaCl did not alter the IR response, although the change in density was sufficient to cause the IR-compacted sludge to float instead of sink.

Adding a very large amount of anionic detergent (enough to make the final solution 1%) changed the appearance of the IR-induced compaction in that the agglommerating floc particles seemed larger and smoother but did not appear to change their rate of settling. Hexane and ethyl acetate extractions introduced complicating factors in that solvent residuals subsequently caused the compacting sludge to float. Nevertheless it was possible to conclude that the IR activity was not being extracted away.

EFFECT OF LIGNOSULFONATE AND ADDED POLYELECTROLYTES ON ORDINARY ACTIVATED SLUDGE

This section describes the series of experiments outlined in Item 3 of our letter of March 16, 1978. The experimental design is presented below.



As described briefly in our letter of July 10, 1978, this experiment produced some very interesting results in that the untreated samples showed a strong response to the infrared radiation. Furthermore, the results of polyelectrolyte addition were much more dramatic than had been anticipated. It will be noted that a cationic, non-quaternary polyelectrolyte (Purifloc C-31, Dow) was used in place of the Chitosan. This substitution was made on the basis of solubility considerations. In retrospect, Chitosan would probably have performed as well.

The compositions of the test mixtures are summarized below:

1) No chemical addition, Bolton Sludge, 2 liters
2) No. 1 plus 15 ml of a 1% solution of Purifloc C-31
3) No. 1 plus 40 ml of 1% lignosulfonate solution
4) No. 1 plus 15 ml of Purifloc plus 40 ml lignosulfonate

The mixtures were aerated and fed irregularly with 25 ml of a solution containing 24 g dextrose, 5.0 g glycine and 800 mg disodium hydrogen phosphate per liter. The type of food and feeding schedule were designed to encourage bulking. The addition of reagents was begun as

soon as bulking began to develop. Feeding was done in such a manner as to minimize salt buildup. Irradiations were conducted for 15 minutes in 10 ml graduates at a distance of 50 cm. The experimental results which are reported as $\frac{\text{volume of control sludge}}{\text{volume of IR compacted sludge}}$ are presented below in Table 1.

Table 1

Effect of Lignosulfonate and Polyelectrolyte on IR-Compaction

	Time	Run 1	Run 2	Run 3	Run 4	Run 5
No Additions	Initial	2.12	1.65	1.76	1.81	1.61
Added Polyelectrolyte*	Initial	2.0	1.0			
Added Lignosulfonate	Initial	1.45	1.47	1.54	1.63	
Added Polyelectrolyte Plus Lignosulfonate*	Initial	1.8	1.0			
No Additions	12 hrs.	1.49	1.34	1.59		
Added Polyelectrolyte*	12 hrs.	0.8				
Added Lignosulfonate	12 hrs.	1.53	1.18	1.47		
Added Polyelectrolyte Plus Lignosulfonate*	12 hrs.	1.4				
No Additives	24 hrs.	1.01	1.02	1.03	1.03	
Added Polyelectrolyte*	24 hrs.	1.0				
Added Lignosulfonate	24 hrs.	1.02	1.07	1.06	1.03	
Added Polyelectrolyte Plus Lignosulfonate*	24 hrs.	0.8				

* The presence of polyelectrolyte compacted the sludge to 5-10% of the original volume thus making comparative measurements difficult to obtain.

Visual inspection indicated the heavy involvement of filamentous organisms after 24 hours, thus making the last series of observations somewhat questionable. The added lignosulfonate increased the degree of bulking about 10% and may have decreased the measured ratios somewhat. A statistical analysis was performed on the data in an effort to resolve these and other questions. Georgia Tech's CYBER 74 multiprocessor computer system was used in combination with the SPSS software to perform an analysis of variance and t-tests on the data presented in Table 1 . The results of this work are presented below.

- - - ANOVA - - -

RATIO
BY POLY
LIGNO
TIME

SOURCE OF VARIATION	SUM OF SQUARES	DF	MEAN SQUARE	F	SIGNIF OF F
MAIN EFFECTS	2.350	4	.588	10.095	.001
POLY	.294	1	.294	5.060	.037
LIGNO	.042	1	.042	.719	.407
TIME	2.128	2	1.064	18.283	.001
2-WAY INTERACTION	.210	5	.042	.723	.615
POLY LIGNO	.054	1	.054	.930	.347
POLY TIME	.032	2	.016	.272	.764
LIGNO TIME	.138	2	.069	1.184	.328
3-WAY INTERACTION	.158	2	.079	1.361	.280
POLY LIGNO TIME	.158	2	.079	1.361	.280
EXPLAINED	2.719	11	.247	4.247	.003
RESIDUAL	1.106	19	.058		
TOTAL	3.825	30	.127		

31 CASES
0 MISSING (0 PCT)

The interpretation of the above results is that the effect of added POLYelectrolyte is significant (0.037). The true significance is probably greater than shown on account of the fact that the degree of settling produced by the polyelectrolyte was tenfold greater than that which was observed in its absence. Thus when these samples were subjected to infrared light it was very difficult to establish ratios. It is probably more accurate to say that the polyelectrolyte produced dramatic changes in the settling characteristics of the sludge, regardless of whether or not it was subsequently exposed to infrared light. The influence of the added LIGNOsulfonate on the compaction ratios is not highly significant (0.407). In this case, the ease of measurement and number of comparisons are in better balance so that it is safe to say that the sludge responded to the infrared light in about the same way whether or not the light was on. Time was the most significant factor (0.001). Thus it is virtually certain that the length of time which the bulking has existed has the strongest influence on whether or not the sludge will respond to infrared light. This is probably related to the physical/chemical properties of the sludge and may explain why not all sludges respond equally to IR light. The T-test shown on the next page is supportive of the ANOVA conclusion regarding the effect of the polyelectrolyte. However, it is not significant in itself. The means and standard deviations are presented as a part of this data.

The next T-test examined the effect of lignosulfonate on the compaction ratios and like the ANOVA data was not statistically significant. The printout is presented on the next page.

--- T - TEST ---

RATIO

	GROUP 1 NO POLY	GROUP 2 WITH POLY
NO.OF CASES	23	8
MEAN	1.3874	1.2250
STD. DEV.	.3157	.4590
STD. ERROR	.0658	.1623

F-VALUE	2.11
2-TAIL PROB.	.170

	T-VALUE	DF	P-VALUE
POOLED VAR. EST.	1.11	29	.275
SEPARATE VAR. EST.	.93	9.41	.378

--- T - TEST ---

RATIO

	GROUP 1 NO LIGNO	GROUP 2 WITH LIGNO
NO.OF CASES	16	15
MEAN	1.3912	1.2967
STD. DEV.	.4147	.2898
STD. ERROR	.1037	.0748

F-VALUE	2.05
2-TAIL PROB.	.188

	T-VALUE	DF	P-VALUE
POOLED VAR. EST.	.73	29	.470
SEPARATE VAR. EST.	.74	26.88	.466

The last T-test compared time period 1 (initial) with time period 3 (24 hours). The results showed that time is a very significant factor in determining the degree of response to irradiation. These results are summarized below.

- - - T - TEST - - -

RATIO

	GROUP 1 INITIAL	GROUP 2 24 HOURS
NO.OF CASES	13	10
MEAN	1.6031	1.0070
STD. DEV.	.3300	.0757
STD. ERROR	.0915	.0239
F-VALUE	18.99	
2-TAIL PROB.	.000	

	T-VALUE	DF	P-VALUE
POOLED VAR. EST.	5.57	21	.000
SEPARATE VAR. EST.	6.30	13.61	.000

TOC measurements were made on the initial supernatants. The results of these tests indicated that the untreated supernatant was the lowest and the lignosulfonate-treated the highest in TOC. The higher levels of TOC in the polymer-treated supernatants probably represent unreacted polymer since larger-than-usual amounts were added. The fact that the doubly treated supernatant showed a TOC which was lower than that observed with lignosulfonate alone indicates that the anionic (lignosulfonate) and cationic (Purifloc C-31) polymers are removing each other from solution. This conclusion is supported by the observation that this supernatant lacks the brown lignosulfonate color.

Mr. Poythress reports attempting to use polyelectrolytes to enhance settling characteristics both on the bench and in the Rocky Creek facility itself. Cationics are effective 90% of the time and when they don't work, anionics do. The sludges remained biologically effective. In-plant use was not successful however, due largely to mixing problems.

ISOLATING THE EFFECTS OF TEMPERATURE AND INFRARED RADIATION

As soon as the magnitude of the heat-induced compaction began to be appreciated, the authors sought to coneive of an experimental design which could isolate the two effects. A simple plan for maintaining a constant temperature during irradiation involved sheathing the graduated cylinder which was being irradiated in a stream of flowing water. Hopefully a thermal equilibrium would be established at a temperature which was not very different from that of the water itself. Preliminary experiments established that temperatures in the range of 27-30^{o}C (depending on the flow rate of the water) could be maintained using Atlanta tap water.

A series of experiments was set up on the basis of this information in which samples of sludge (50 ml) were irradiated at a distance of 20 cm for 15 minutes while encircled by a sheath of running water which was flowing at such a rate as to maintain the temperature at 28^{o}C. Comparison samples were immersed in a water bath away from the light at 28^{o}C while still other samples were held in the dark at room temperature (22^{o}C). A comparison of the sludge volumes in the 22^{o} controls with those in the irradiated samples provides an estimate of the degree of response due to both heat and light. A similar comparison of the compacted sludge volumes in the control at 28^{o}C and the infrared-exposed samples at 28^{o}C isolates the effect of light. A final comparison between the non-irradiated sludge volumes at 22^{o}C and at 28^{o}C provides a measure of the degree of response due to heat alone. The results of eight replicate tests are presented in Table 2.

Table 2

Effects of Temperature and Infrared Radiation

Run No.	Volume of Control at 22°C / Volume of IR at 28°C	Volume of Control at 28°C / Volume of IR at 28°C	Volume of Control at 22°C / Volume of IR at 28°C
1	1.37	1.36	1.01
2	1.21	1.08	1.12
3	1.27	1.12	1.14
4	1.20	1.13	1.04
5	1.24	1.22	1.02
6	1.43	1.43	1.01
7	1.09	1.07	1.02
8	1.17	1.07	1.09

A statistical analysis of the data was performed using the T-test in order to help answer the following questions:

1. Is the degree of response to heat and infrared light together significantly different from that due to IR alone? A comparison of Columns 1 and 2 provides an estimate. The statistical evidence ($t = 3.02$, $p < 0.01$) indicates that there is a highly significant difference between the response to both factors and the response to IR alone. Thus the effect of heat cannot be ignored.
2. Is the degree of response to both heat and infrared light significantly different from that due to heat alone? In this case a comparison of Columns 1 and 3 provides the estimate ($t = 4.07$, $p < 0.005$). This means that there is a very highly significant difference between the degree of response to both factors and the response to heat alone. Thus the effect of IR cannot be ignored either.

3. Is the degree of response to infrared radiation alone significantly different from that due to heat alone? A comparison of Columns 2 and 3 provides the required information ($t = 2.06$, $p \sim 0.07$). While the level of significance is not as large as was seen in the first two cases, there is still a significant difference.

Subsequent experiments with other batches of sludge have produced similar results. It has been noted that the differences between the factors is dependent upon the nature of that particular sludge, upon the temperature differential and upon the intensity of the irradiation. Qualitatively it has been found that the temperature differential must be at least $5^{o}C$ in order to produce an effect which can be statistically verified. Similarly, the intensity of the light and the nature of the sludge should be such that at least a 30% reduction in the volume can be brought about by irradiation. This general information is being applied to related experiments designed to assess the relative importance of irradiation and heat on a variety of wastewater sludges.

CONCLUSIONS

Infrared radiation in combination with heat has a compacting effect on bulking wastewater sludges in general. The significance of the infrared portion of this activity has been statistically established using sludge from Macon's Rocky Creek facility. This facility treats a mixture of pulp-mill waste and domestic waste and it would appear that the pulp-mill contribution, in addition to creating the bulking in the first place, was responsible for making the IR response so dramatic as to be instantly recognizable. Changes in the composition of this waste stream due to the institution of pollution control measures and an increased emphasis on water reuse have reduced the intensity of this response to the point at which repeated observations and statistical methods are necessary to recognize the contribution of the infrared radiation to settling. The experimental work is nearing completion and a final report can be expected in the near future.

B-491

DRAFT FINAL REPORT

EES/GIT Project B-491

EFFECT OF INFRARED RADIATION ON COMPACTION OF MUNICIPAL WASTEWATER SLUDGES

NSF GRANT ENV 77-15086

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December 1978

ENGINEERING EXPERIMENT STATION
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DISCLAIMER

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EXECUTIVE SUMMARY

The activated sludge process is widely employed for the treatment of wastewaters from both domestic, industrial and mixed sources. The success of this treatment is dependent upon the separation of solids in the secondary sedimentation tank and upon their concentration for subsequent return to the aeration tank. Therefore, it is not surprising that bulking (poorly settling) sludges exacerbate difficult disposal problems which are already one of the major headaches associated with wastewater treatment. It would thus seem worthwhile to explore any process which had the possibility of reducing the extra load of waste sludge caused by bulking conditions or which could bring about compaction of wastewater sludges in general. New methods of sludge debulking which do not involve the use of chlorine are particularly interesting since it has already been established that this practice, while effective, leads to the production of potentially hazardous chloroorganic materials.

Since the authors had noted the occurrence of an unusual infrared-induced sludge compaction phenomenon which took place at Macon, Georgia's Rocky Creek wastewater treatment facility, a research program was proposed to and subsequently funded by the National Science Foundation to investigate the nature of the phenomenon in the hope that a method for making the IR-enhanced settling generally applicable could be demonstrated.

Since the original studies performed in connection with the design and monitoring of a pilot wastewater treatment facility at Macon, Georgia, which are summarized in the first section of this report, the relative proportions of the waste streams and their characteristics have been in a state of constant change. The compaction phenomenon as observed during the operation of our own mini-pilot facility was not nearly as pronounced as it had been in earlier years. It is, however, still recognizable. Upon the evaluation of the results of these studies and as an outgrowth of the bench testing work conducted in the Experiment Station's own laboratories, the Principal Investigators were forced to conclude that a continued investigation of ways to apply the phenomenon to the improvement of bulking sludges in general did not seem to warrant carrying out the Phase II studies outlined in the original proposal. The factor responsible for the dramatic nature of the phonemenon at Macon appears to be associated with the pulpmill wastes which are also responsible for inducing the bulking in the first place. Although the 1R phonomenon can be induced in ordinary activated sludge as a result of deliberately altering the feed, it appears to be a transient occurrence which preceeds the onset of true filamentous bulking. The performance of this work fulfilled the original objectives of the Phase I studies. Additional studies have been carried out to further strengthen these conclusions and provide new leads for further studies of a somewhat different nature.

A factorial experiment was designed to investigate the effect of temperature and irradiation on the filterability of the sludge. As expected, there was a significant improvement in filterability at the warmer temperatures. There was no significant difference which could be attributed to the irradiation. It might be noted however, that application of this well-established effect might be generally helpful in wastewater treatment if very low cost heat were employed to elevate the temperature of wastewater sludges prior to dewatering, i.e.; solar energy or waste heat.

Studies aimed at defining the wavelength of maximum response were performed on a conventional infrared spectrophotometer and hinted at a maximum response at 2200 cm^{-1} and 2300 cm^{-1}. This evidence however, did not prove to be statistically significant and would have to be reexamined using a more intense variable wavelength source. If substantiated, these observations could be of fundamental importance as there are not many characteristic IR bands in this region.

There was a memory effect in that irradiated sludge when resuspended still settled better than untreated sludge. Thus, the changes produced by irradiation are only partially reversible. Changes in pH, salt concentration, the addition of an anionic detergent and solvent extractions did not appear to alter the response.

A factorial study with added lignosulfonate and added polyelectrolytes on ordinary activated sludge under conditions designed to induce bulking showed that the effect of added polyelectrolyte was highly significant in that vastly improved settling characteristics were produced regardless of whether or not the treated sludge was subsequently exposed to infrared light. The addition of lignosulfonate did not significantly alter the response to the infrared radiation. This finding was quite surprising to the principal investigators since we had originally presumed the lignosulfonate component of the pulp mill wastes to be involved either in the absorption of the infrared radiation or in the creation of excess anionic charge on the surface of the bulking sludge particles. Now it would seem that perhaps the presence of wood sugars or some other component of the pulp mill wastes may be upsetting the ability of the biological system to produce a normal sludge. The fact that the length of time which the bulking has existed has the strongest influence on whether or not the sludge will respond to infrared-radiation suggest that an infrared-responding stage may be part of the normal course of events when an activated sludge wastewater treatment process is subjected to stresses ultimately resulting in filamentous bulking. This conclusion has been supported by other experiments in which the IR phenomenon was successfully induced in a variety of municipal sludges.

Experiments performed at Macon have demonstrated that polyelectrolytes do enhance the settling characteristics of activated sludges and that, if added at an early stage, do not interfere with the biological effectiveness of the system. In-plant use was not successful however, due largely to mixing problems.

Another series of experiments was performed which demonstrated that heat alone was capable of producing a compacting effect which was very similar to that observed with the infrared radiation alone. The only differentiating feature was the stronger memory effect exhibited by the irradiated sludge. A series of experiments were performed in an effort to statistically isolate the effects of heat and exposure to infrared irradiation. The results of these experiments indicate that both effects are statistically significant and that they are different from each other.

These experiments are described in greater detail in the sections which follow.

EARLIER STUDIES AT MACON

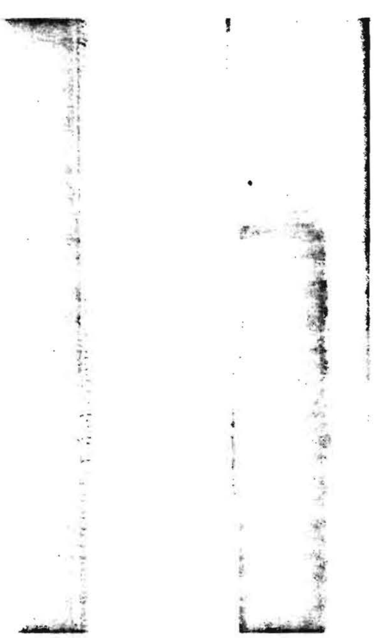
In 1969, two of the three principal investigators participated in the design and monitoring of a pilot wastewater treatment facility at Macon, Georgia. During this study period in which two variations of a typical activated sludge process were employed to stabilize the mixed wastes from a manufacturing plant (Armstrong Cork), a pulp mill (Georgia Kraft), and a municipal component, bulking was a continuous problem. As the tests progressed it was noted that the type of bulking responsible for the poor settling characteristics of the treated wastewaters did not appear to involve an overgrowth of filamentous organisms as is typically the case. Furthermore, it was noted that the bulky sludge rapidly compacted if exposed to sunlight while companion samples shielded from the light retained their bulking characteristics. An example of these differences is shown in Figure 1. At this time, the input to the pilot facility was composed of the following contributions from the three sources indicated below:

Armstrong Crok............20%
Georgia Kraft.............60%
Municipal.................20%

The characteristics of the input stream are outlined in Table I, and presented graphically in Figures 2 through 9. Since that time, a full scale facility has been placed in operation at Macon. The bulking problem remains. The input stream characteristics have changed somewhat with Armstrong Cork choosing to treat its own wastes separately. The proportional contribution from the pulp mill has decreased as water recycling and in-plant recovery of

0 Minutes

10 Minutes



20 Minutes

30 Minutes

TABLE 1

Input Stream Characteristics During Pilot Study Period*

Property Measured	Month	Armstrong Cork (20%) Range	Armstrong Cork (20%) Average	Georgia Kraft (60%) Range	Georgia Kraft (60%) Average	Municipal at Pio Nono Outfall (20%) Range	Municipal at Pio Nono Outfall (20%) Average
pH	April	5.7-7.1	6.4	8.9-10.0	8.4	7.0-7.3	7.2
	May	6.2-7.7	6.8	7.0-10.2	9.9	6.8-7.2	7.1
	June	6.0-7.0	6.6	9.7-10.4	10.1	7.0-7.5	7.2
	July	6.8-7.2	6.9	8.6-9.9	9.7	7.1-7.6	7.3
	Aug.	NA	NA	9.8-10.2	10.0	7.2-7.7	7.5
	Sept.	NA	NA	9.1-9.8	9.4	7.2-7.7	7.4
	Oct.	5.9-7.3	6.7	9.5-10.4	10.0	7.3-7.7	7.5
	Nov.	5.7-7.1	6.3	7.8-10.4	9.6	7.2-7.7	7.5
	Dec.	6.1-6.8	6.3	NA	NA	7.5-7.6	7.6
Total Solids	April	3046-6482	4365	794-1078	892	282-540	436
(mg/l)	May	3360-4308	3839	680-1294	963	354-714	550
	June	2098-4908	3844	742-1346	1019	478-1020	643
	July	2420-4904	3624	702-1364	1153	474-726	590
	Aug.	NA	NA	880-1150	1040	155-722	506
	Sept.	NA	NA	705-1000	879	350-790	617
	Oct.	3830-9840	6038	890-1545	1124	480-685	561
	Nov.	2660-8820	4299	570-2130	1460	450-680	561
	Dec.	3820-6000	4783	NA	NA	540-620	571

*1970 - We are grateful fo the City of Macon for supplying these data.

Table 1 (Continued)

Input Stream

Property Measured -	Month	Range	Average	Range	Average	Range	Average
Total Volatile Solids	April	2462-5126	3252	364-702	511	160-448	228
	May	2170-2740	2580	286-670	453	156-492	420
	June	1180-3902	2672	420-678	525	288-482	355
	July	1450-2810	2315	378-754	601	268-380	325
	Aug.	NA	NA	360-535	409	150-482	280
	Sept.	NA	NA	165-310	253	120-415	276
	Oct.	3015-5855	4093	200-690	404	205-400	306
	Nov.	1845-6400	3061	385-870	578	200-410	319
	Dec.	2960-4970	3738	NA	NA	220-340	275
Suspended Solids - (mg/l)	April	1530-3915	2163	53-285	165	105-228	178
	May	1370-2330	1727	45-280	161	45-350	215
	June	760-2480	1628	10-140	92	100-275	202
	July	980-2310	1700	35-155	83	55-275	196
	Aug.	NA	NA	95-150	123	105-210	157
	Sept.	NA	NA	25-76	59	100-205	172
	Oct.	1240-6920	3170	40-140	89	140-240	187
	Nov.	980-3860	2091	80-555	205	80-330	186
	Dec.	2190-4490	3063	NA	NA	180-365	226

TABLE 1 (Continued)

	Month	Range	Average	Range	Average	Range	Average
Volatile Suspended - Solids (mg/l)	April	NA	3235	NA	53	NA	113
	May	1020-1530	1275	NA	NA	NA	70
	June	920-1820	1262	0-100	50	110-210	160
	July	1080-2310	1610	15-65	34	30-230	140
	Aug.	NA	NA	NA	NA	NA	NA
	Sept.	NA	NA	NA	70	NA	70
	Oct.	1120-4740	2160	10-78	34	90-170	123
	Nov.	820-2440	1411	40-280	132	65-300	150
	Dec.	1630-2930	2225	NA	NA	110-165	126
Settleable Solids - (ml/l/hr)	April	80-140	107	2.0-2.5	5.5	6.5-9.0	7.7
	May	30-100	65	0.8-26	4.7	2.5-16	9.7
	June	9-130	86	0.9-2.5	1.8	4.5-17	7.7
	July	30-120	80	0.6-9.0	2.6	6.5-10	7.4
	Aug.	NA	NA	0.5-2.5	1.6	5.0-9.0	7.5
	Sept.	NA	NA	0.8-2.0	1.5	4.5-9.0	7.0
	Oct.	50-180	120	0.1-1.5	0.7	5.5-9.5	7.8
	Nov.	50-140	79	0.7-14	7.3	8.0-10	9.2
	Dec.	80-120	98	NA	NA	7.5-10	9.1

TABLE 1 (Continued)

	Month	Range	Average	Range	Average	Range	Average
BOD (20°C, 5 day) -	Month	Range	Average	Range	Average	Range	Average
(mg/l)	April	1150-1950	1558	260-460	378	160-200	184
	May	800-1700	1384	180-500	342	140-260	191
	June	950-2150	1736	160-580	390	150-320	233
	July	1050-2000	1450	220-500	380	130-290	190
	Aug.	NA	NA	380-760	450	150-200	180
	Sept.	NA	NA	380-440	400	160-220	192
	Oct.	1400-2100	1800	310-580	410	160-240	190
	Nov.	850-1650	1185	200-520	341	160-250	218
	Dec.	1100-1650	1375	NA	NA	180-280	237
COD	April	3500-5380	4102	760-1170	923	360-480	391
(mg/l)	May	2450-4570	3637	480-1300	916	210-480	377
	June	2960-4130	3576	340-1200	905	290-1020	455
	July	2420-6050	3680	560-2000	1170	280-410	370
	Aug.	NA	NA	910-1690	1096	300-410	375
	Sept.	NA	NA	870-1340	1012	380-420	400
	Oct.	4080-10320	6380	910-1380	1080	360-480	400
	Nov.	2760-8720	4245	370-2190	1359	320-450	386
	Dec.	4480-6200	5160	NA	NA	400-640	507

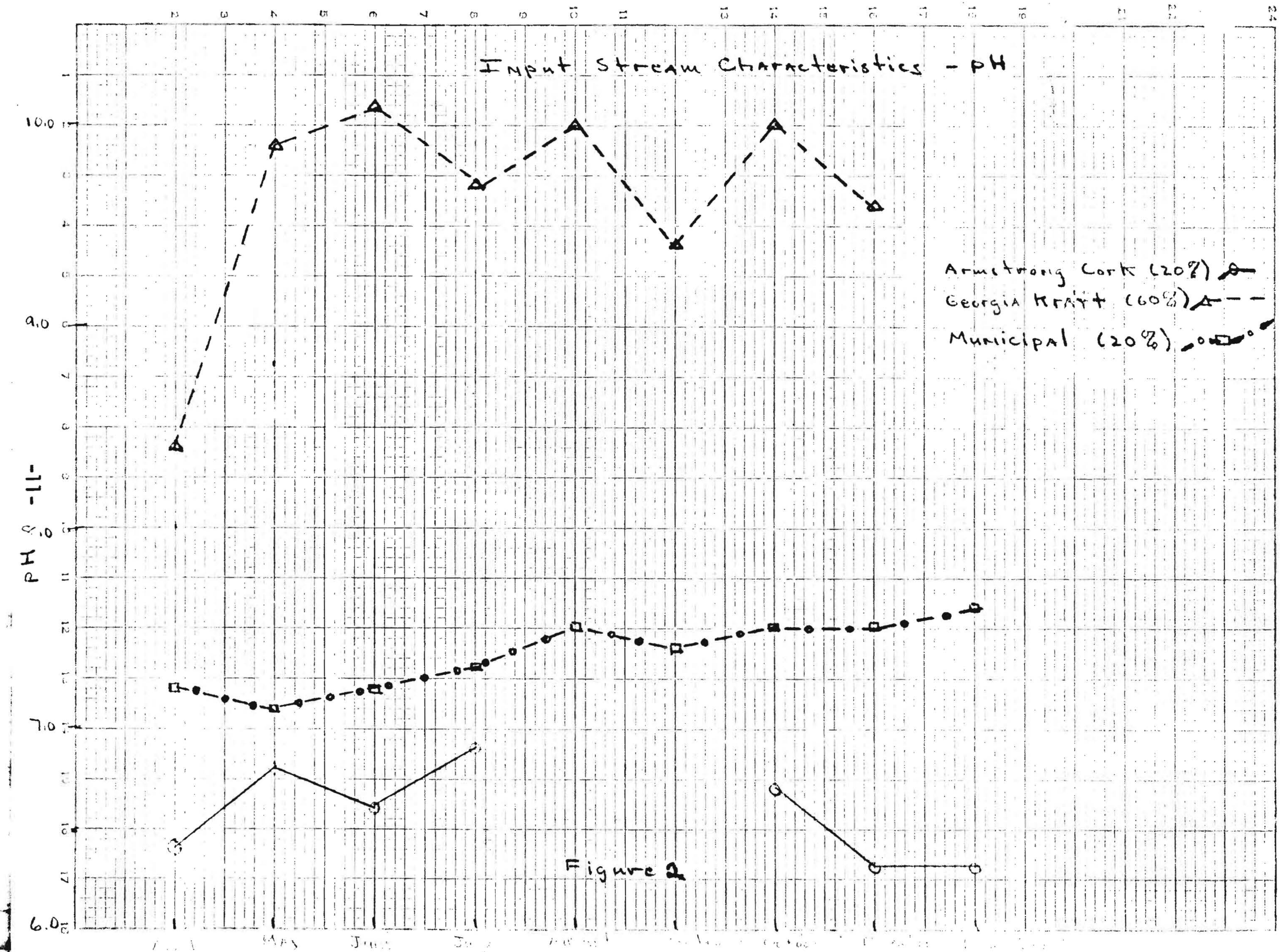

Input Stream Characteristics - pH
10.0
9.0
7.0
6.0
pH
Armstrong Cork (20%)
Georgia Kraft (60%)
Municipal (20%)
May
June

Figure 2

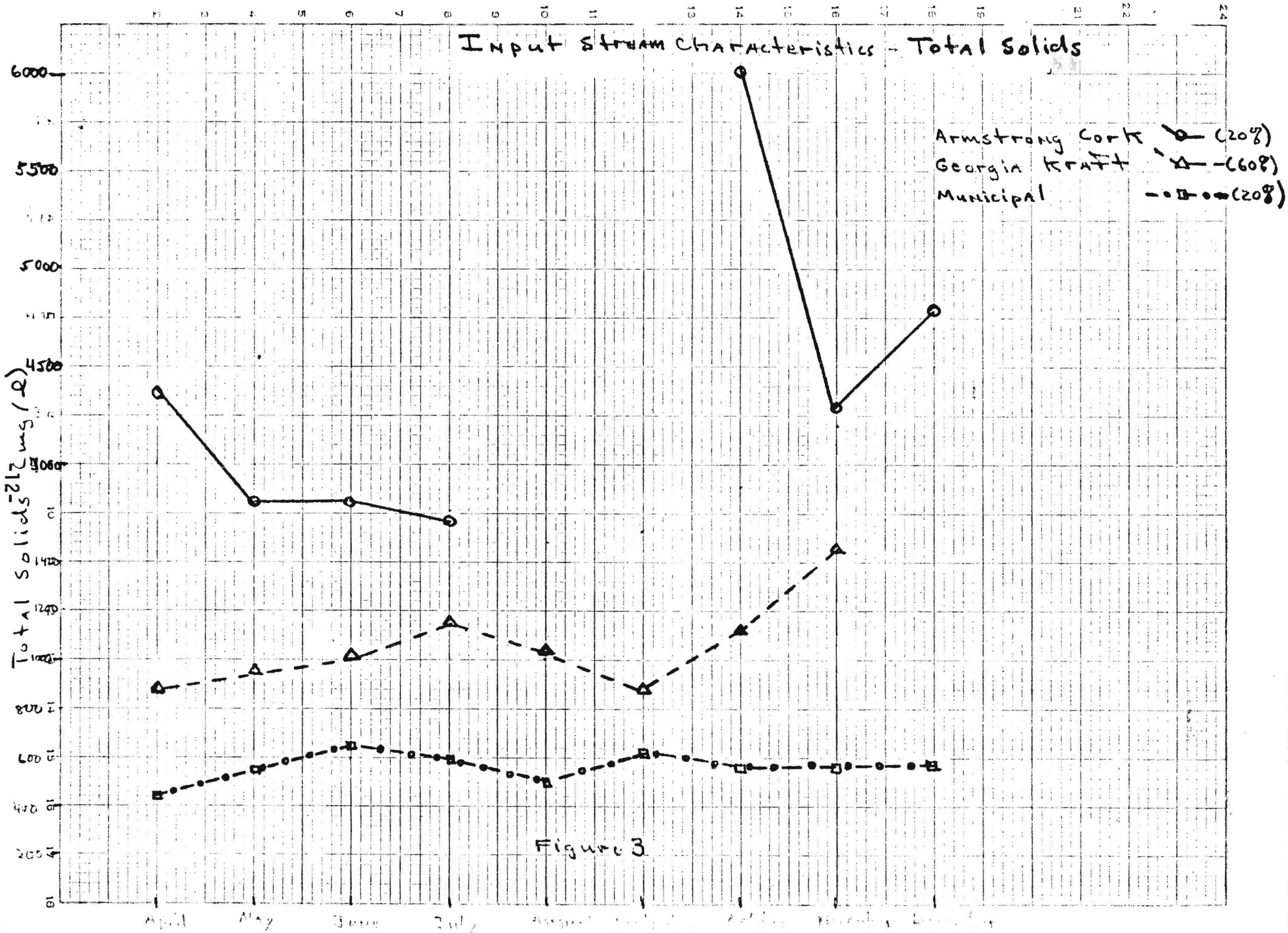

Input Stream Characteristics - Total Solids
Armstrong Cork (20%)
Georgia Kraft (60%)
Municipal (20%)
6000
5500
5000
4500
1400
1200
1000
800
600
400
200
April
May
June
July

Figure 3

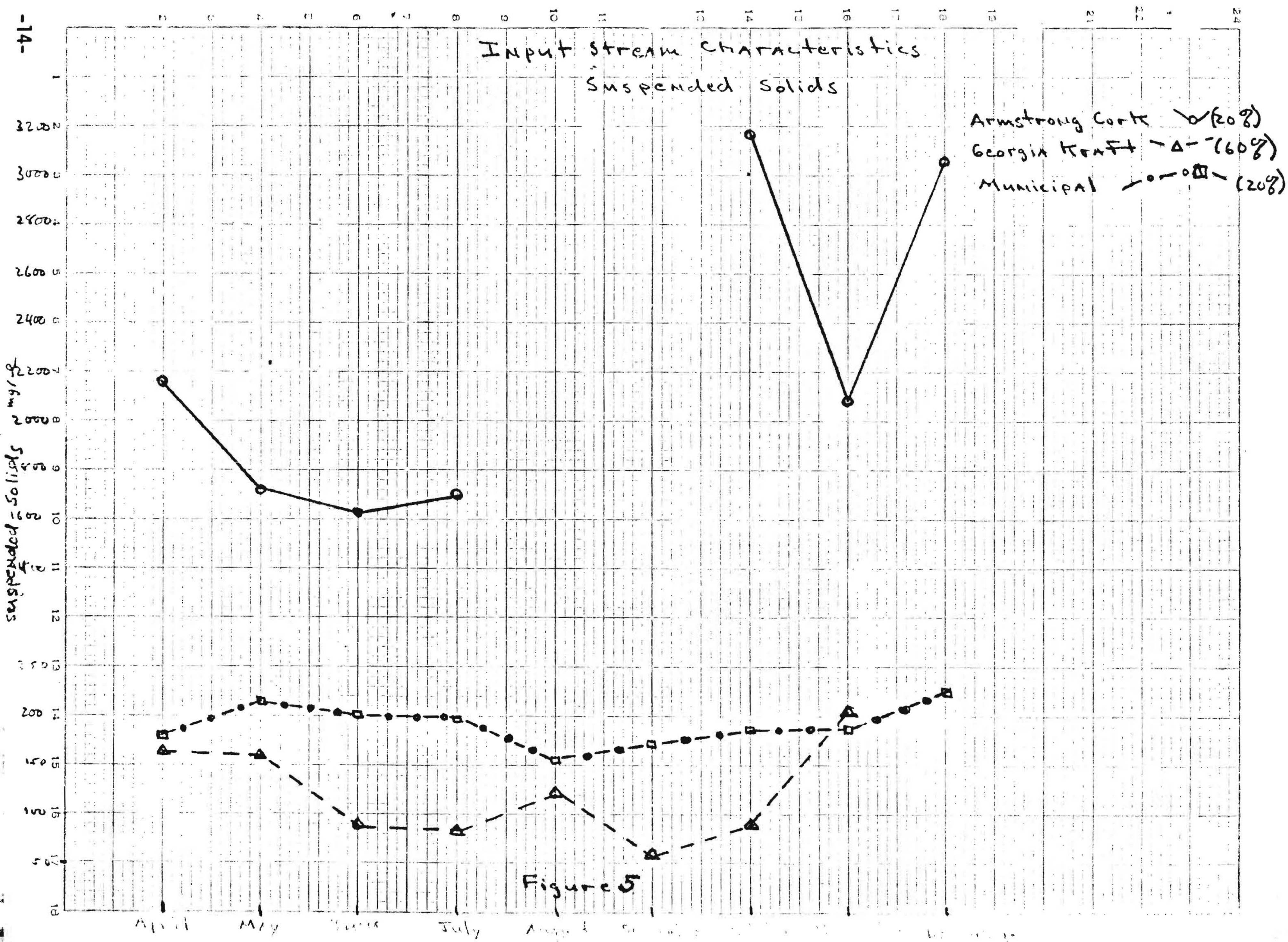
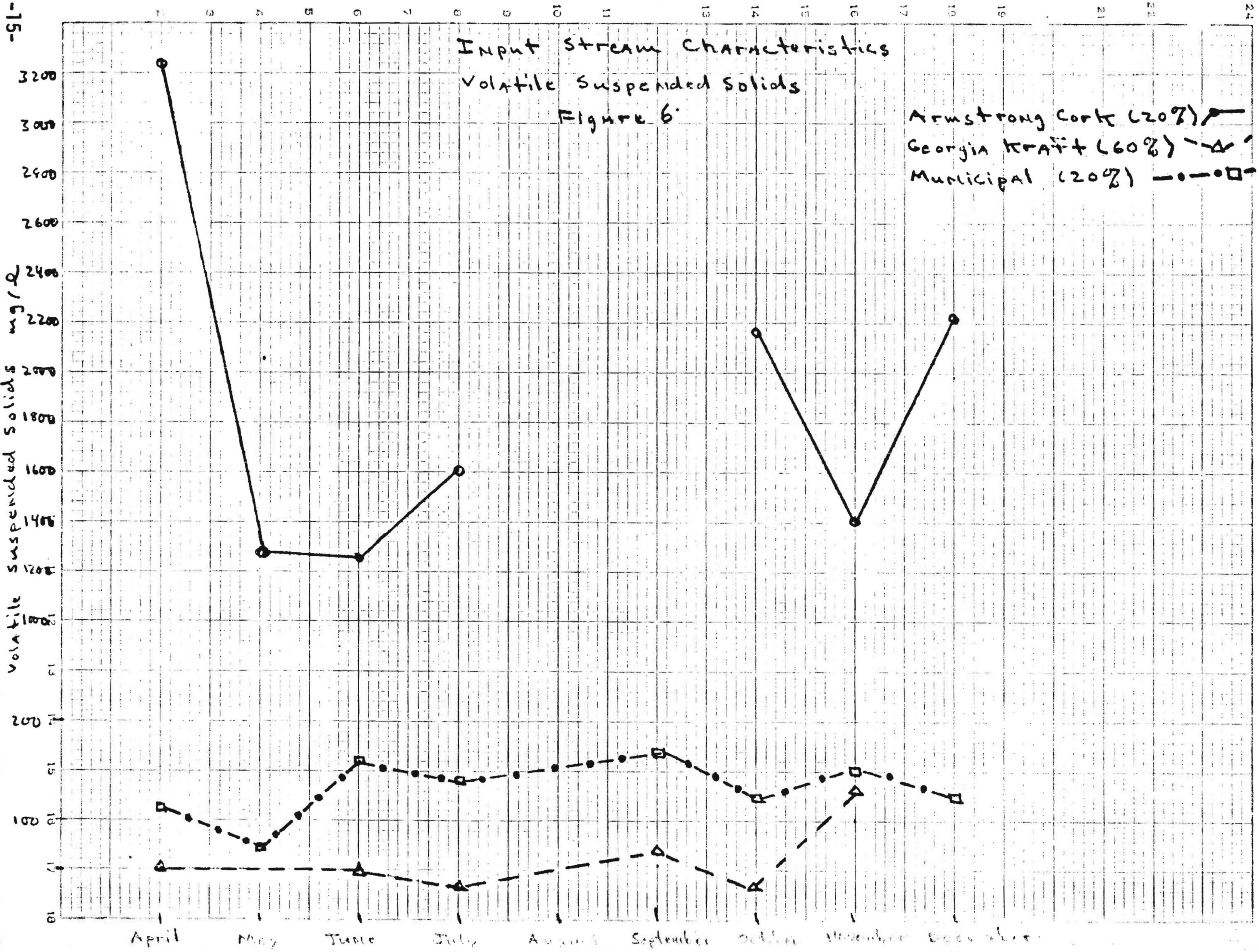
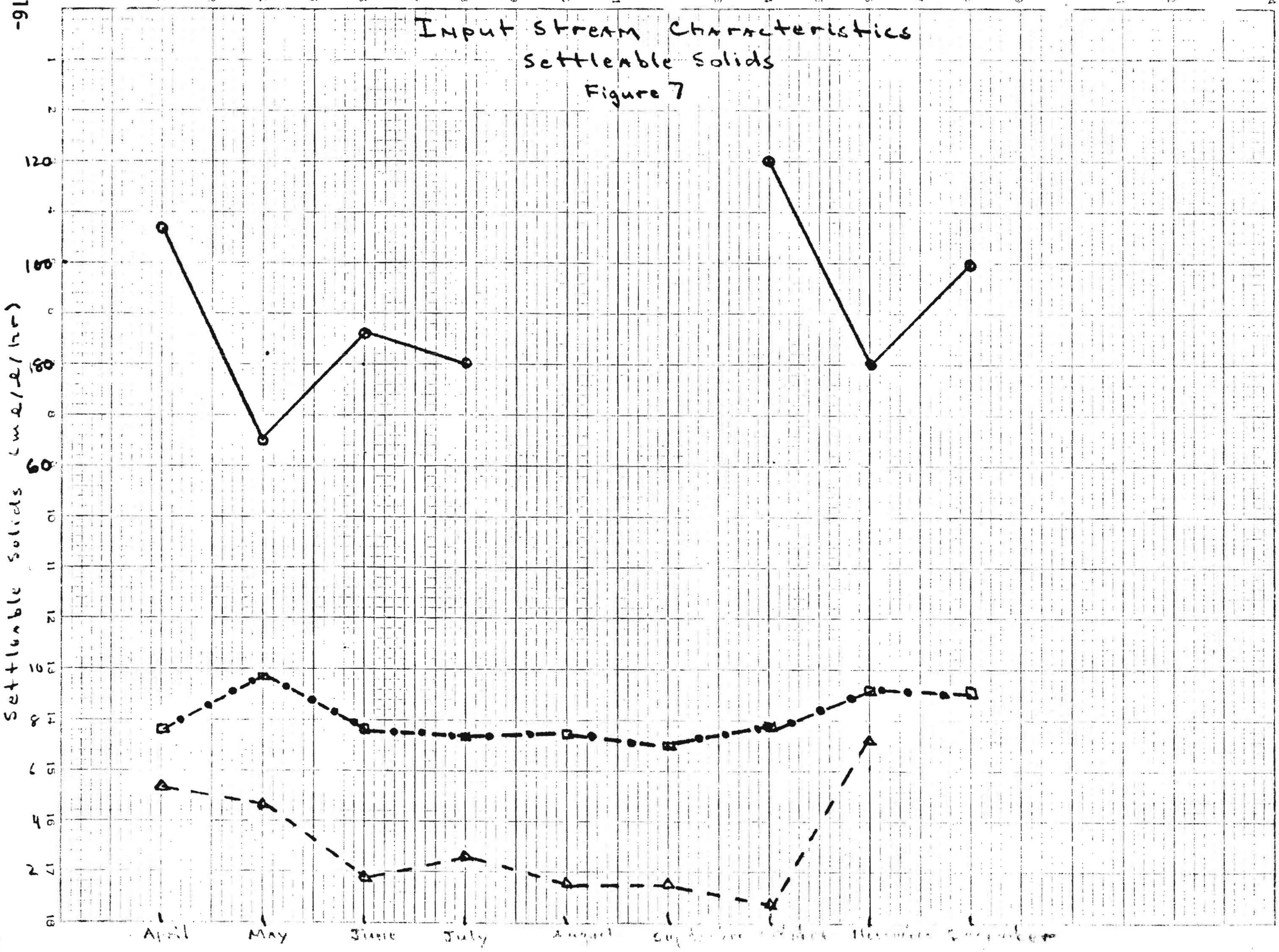
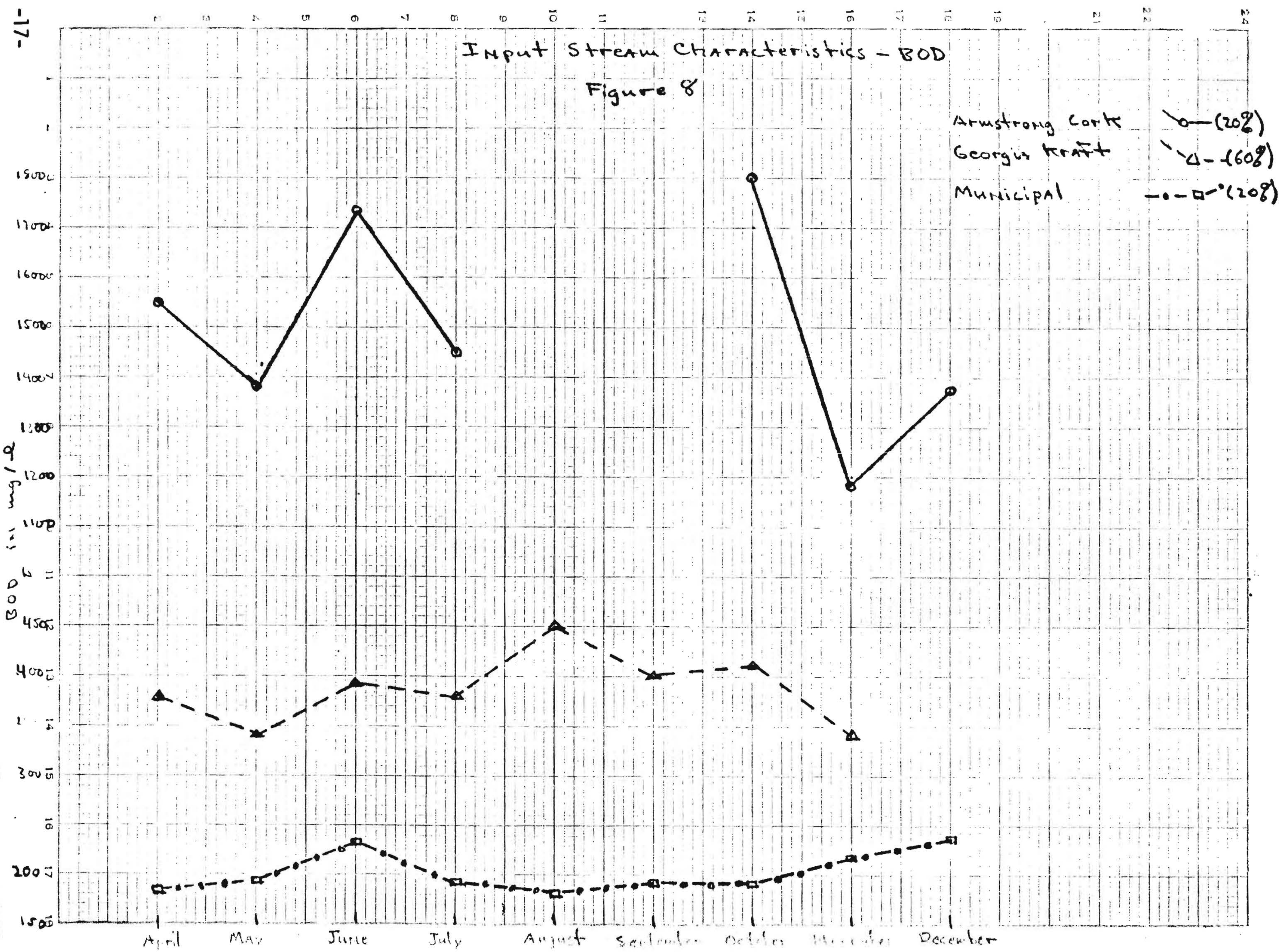

Input Stream Characteristics
Suspended Solids
Armstrong Cork (20%)
Georgia Kraft (60%)
Municipal (20%)
Suspended Solids mg/l
3200
3000
2800
2600
2400
2200
2000
200
150
100
50
April
May
July

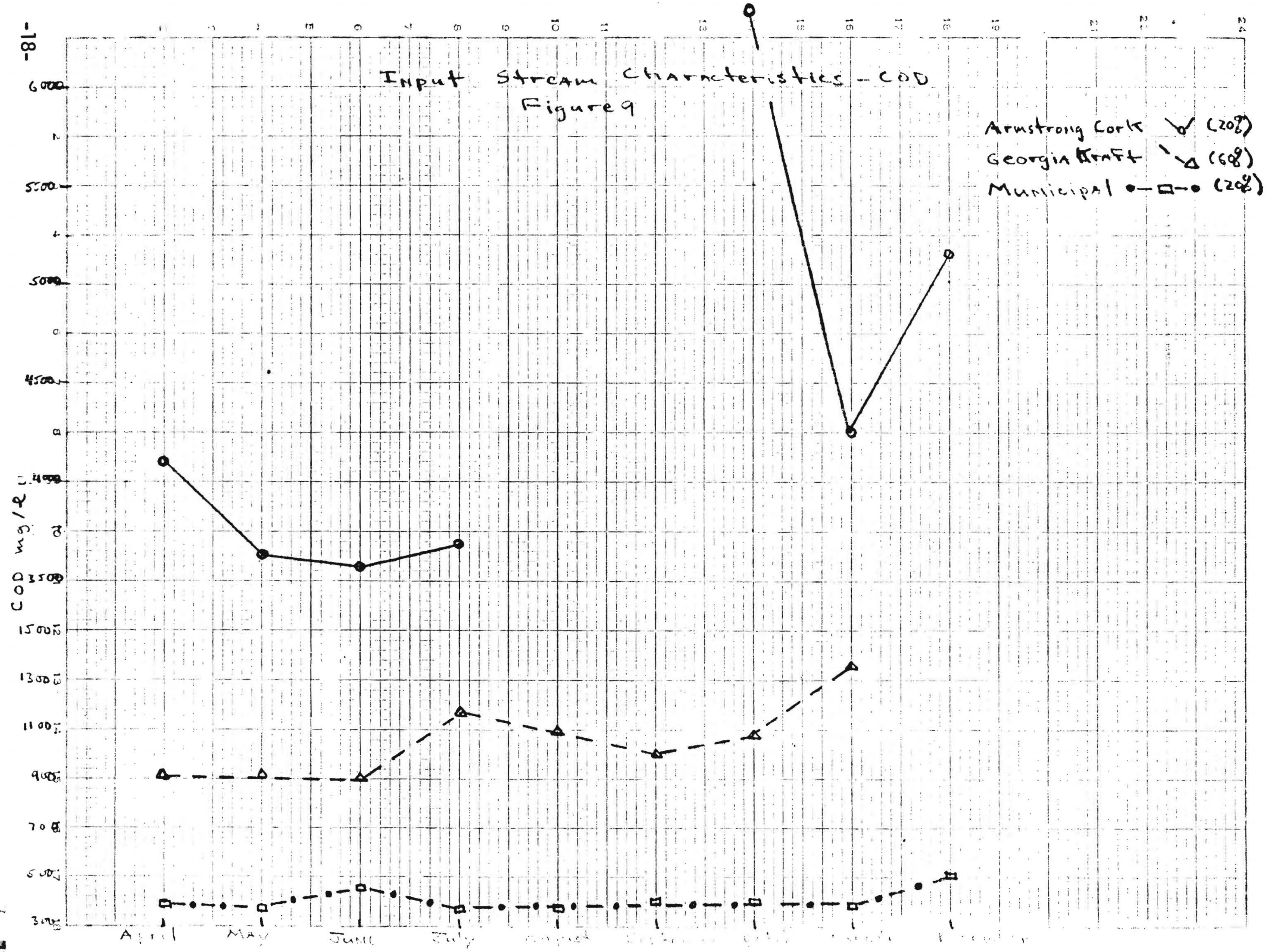
Figure 5



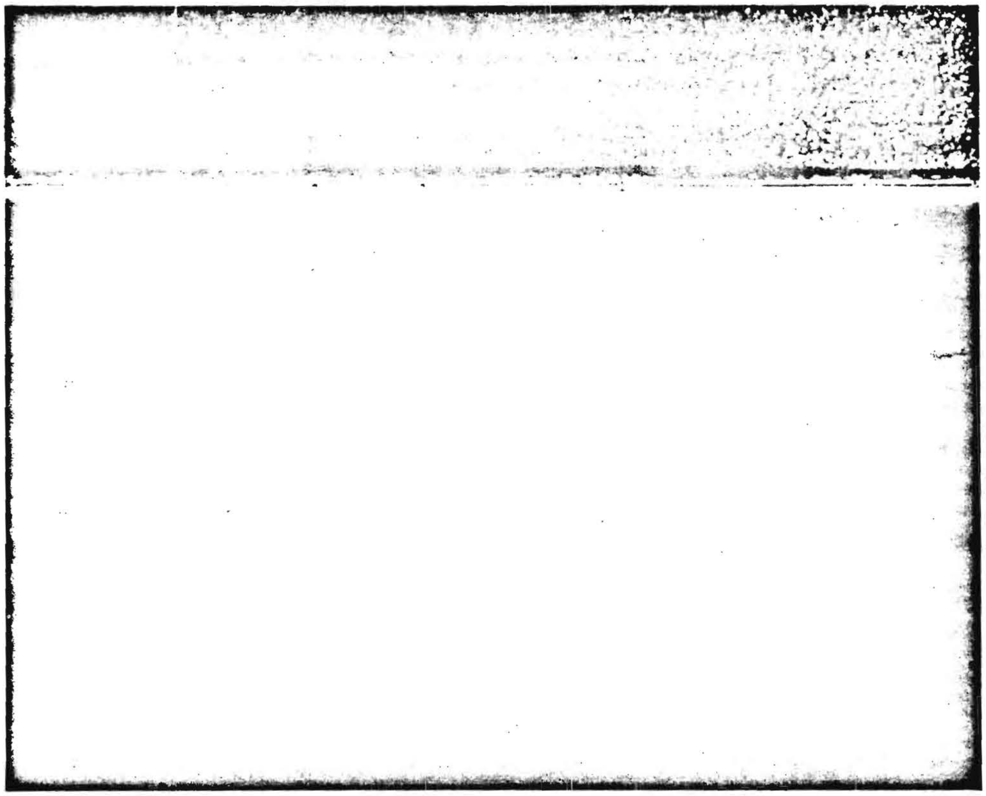
Input Stream Characteristics
Volatile Suspended Solids
Figure 6


Input Stream Characteristics
Settleable Solids
Figure 7
Settleable Solids (ml/l/hr)
120
100
80
60
8
6
4
2
April
May
June
July

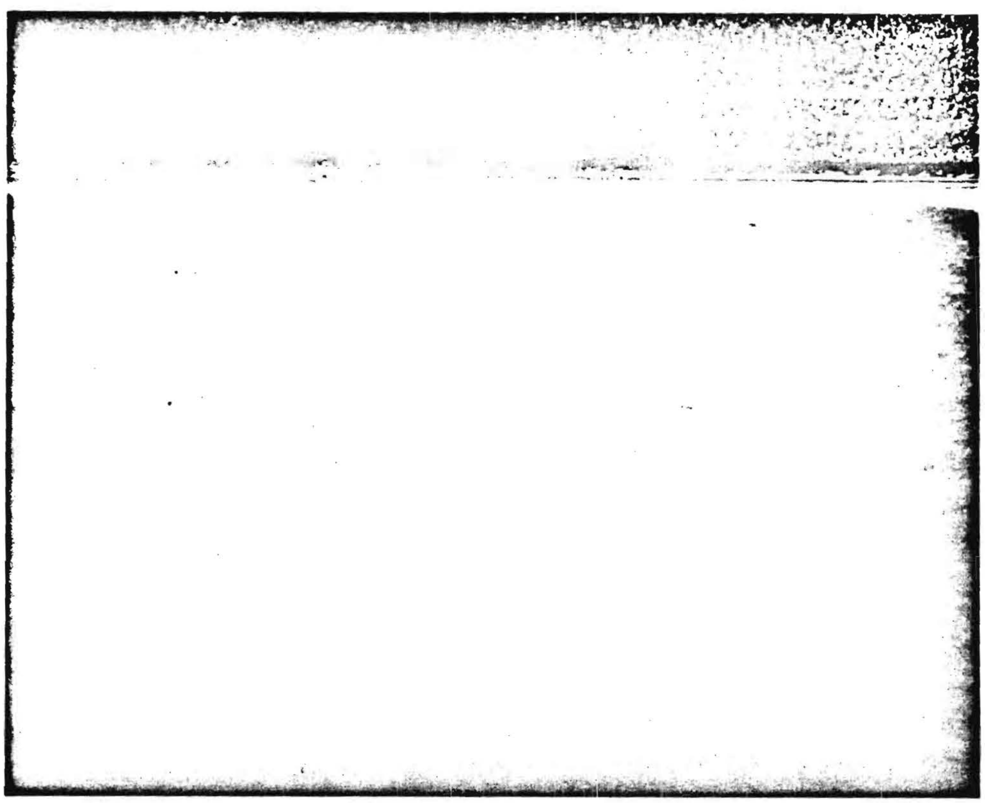

Input Stream Characteristics - BOD
Figure 8
Armstrong Cork (20%)
Georgia Kraft (60%)
Municipal (20%)
BOD in mg/l
1800
1700
1600
1500
1400
1300
1200
1100
4500
4000
3000
200
150
April
May
June
July
August
December


Input Stream Characteristics - COD
Figure 9
Armstrong Cork (20%)
Georgia Kraft (60%)
Municipal (20%)
COD mg/l
6000
5500
5000
4500
4000
3500
1500
1300
1100
900
700
500
300
April
May
June
July

wastes have been put into practice. In the meanwhile, the municipal contribution to the waste stream has increased considerably so that the plant is now operating beyond its designed capacity. As a result of this activity, the compaction phenomenon has become somewhat less striking although it has not disappeared entirely. The results of a more recent test of activity are shown in Figure 10. These changes in the input stream characteristics provided an extra degree of variability which made the interpretation of results more difficult. Since the compaction did continue after the withdrawal of the Armstrong Cork inputs and is not readily observed with municipal wastewaters, the principal investigators feel justified in associating the compaction phenomenon with the pulp mill wastes. Subsequent sections will describe some of the experiments performed in an effort to demonstrate the general applicability of the infrared sludge compaction phenomenon, to characterize the phenomenon, particularly as it relates to the pulp mill component.

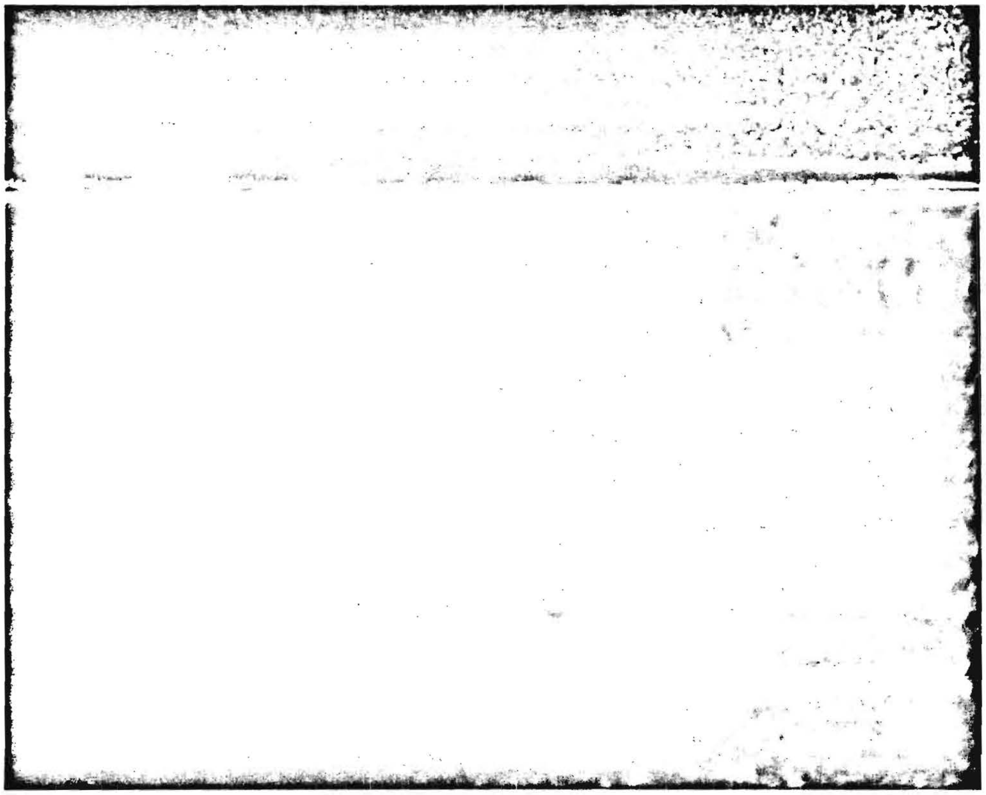


0 minutes

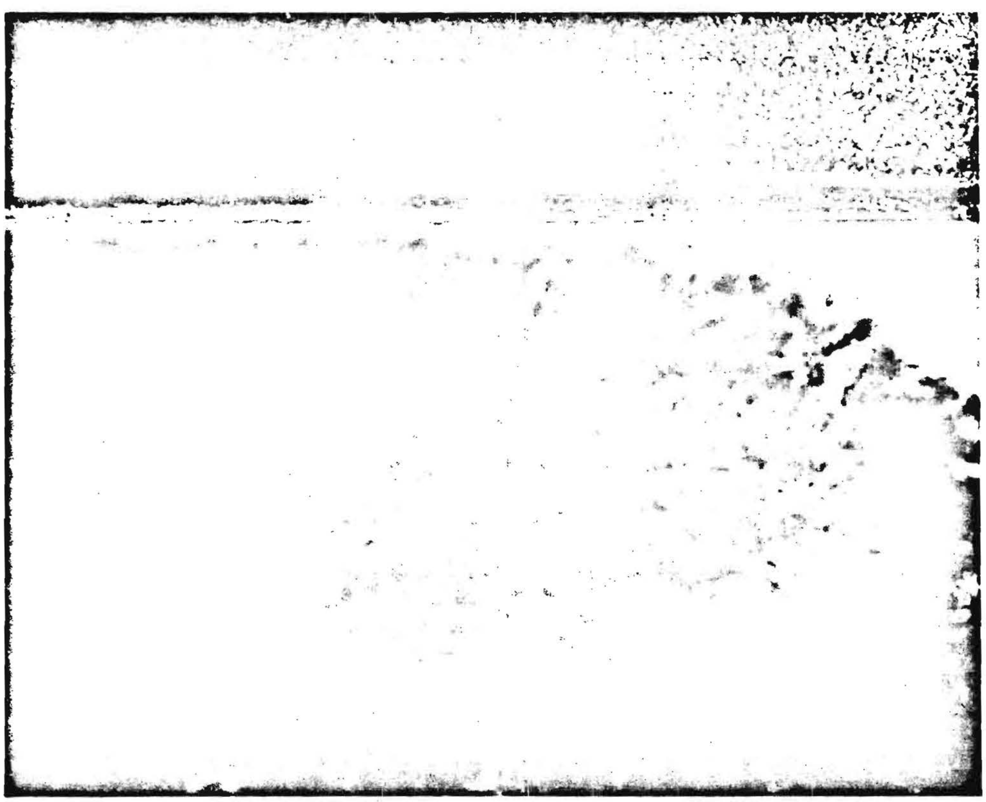


2 minutes

Figure 10a. IR-Induced Settling as a Function of Time

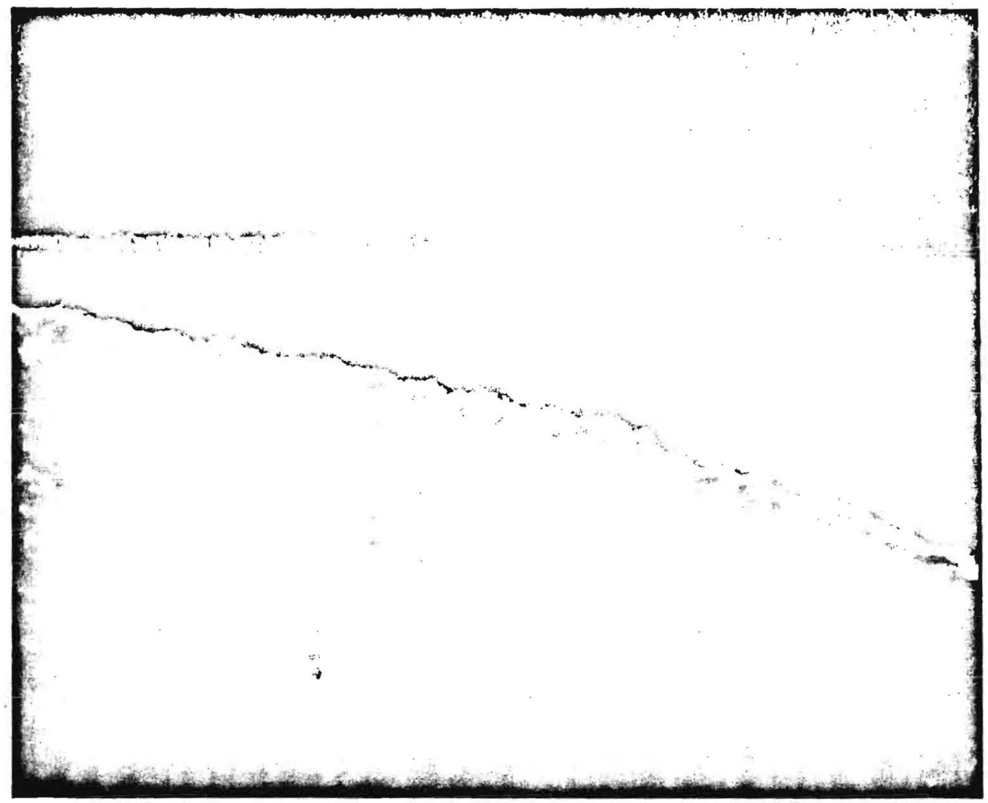


4 minutes



6 minutes

Figure 10b. IR-Induced Settling as a Function of Time



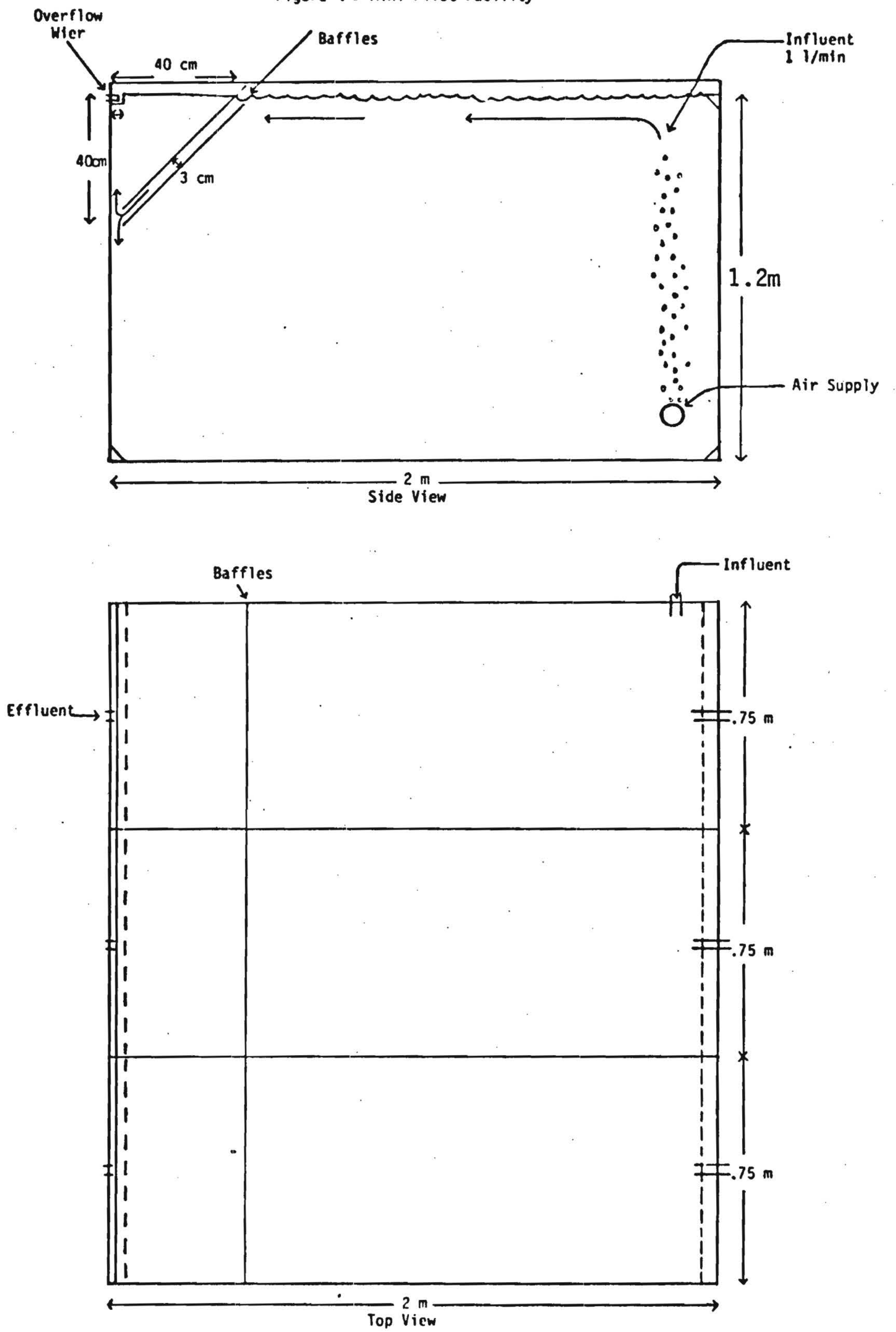
8 minutes

Figure 10c. IR-Induced Settling as a Function of Time

CONSTRUCTION AND OPERATION OF THE MINI-PILOT FACILITY

A three-compartment pilot facility was constructed at Georgia Tech immediately following the award of the contract. The design of this apparatus is shown in Figure 11 and is essentially as outlined in our original proposal. The volume of each compartment was about 1.6 m^3. The general rate of feeding was about 1 l/min. The pulp-mill wastewater stream and the domestic wastewater stream were mixed in varying proportions in an effort to determine the minimum pulp-mill contribution required to have the sludge respond to irradiation. These experiments were confused somewhat by irregularities in the composition of the pulp-mill waste stream as the test period coincided with the institution of new water recycling procedures within the pulp-mill itself. Thus the results were somewhat inconclusive.

Figure 11 Mini-Pilot Facility



DESIGN OF IRRADIATION EXPERIMENTS

Early experiments were conducted using a commercial infrared lamp placed approximately 50 cm away from a 500 or 100 ml graduated cylinder containing freshly agitated sludge. A control cylinder was agitated and allowed to stand in a dark corner for the same length of time. Some of the more recent experiments have employed a 100 ml graduated cylinder placed on a phonograph turntable a specified distance from the light source. In this way unequal convection currents would not be set up along the side of the cylinder nearest the lamp. It was first believed that this precaution would only be important for cases in which the test cylinders were so close to the lamp (within 20 cm) that significant heating would occur. Actual temperature readings are now recorded even when the cylinders are 1.0 or 1.5 meters away from the light source as we have become more aware that heating effects are playing a major role in the compaction phenomenon as it is now being observed in the laboratory.

SETTLING PROFILES

Prior to becoming aware of the possible significance of heat alone as a contributor to the compaction phenomenon, the authors had run a number of experiments designed to obtain a profile of the IR-induced settling phenomenon as compared with settling in the absence of irradiation. A graphical representation of some typical results is presented in Figure 12. Each point on the two uppermost traces is the average from at least three separate runs. It is the recollection of Dr. Ingols that the pre-award curves were more like the lowest trace in the Figure.

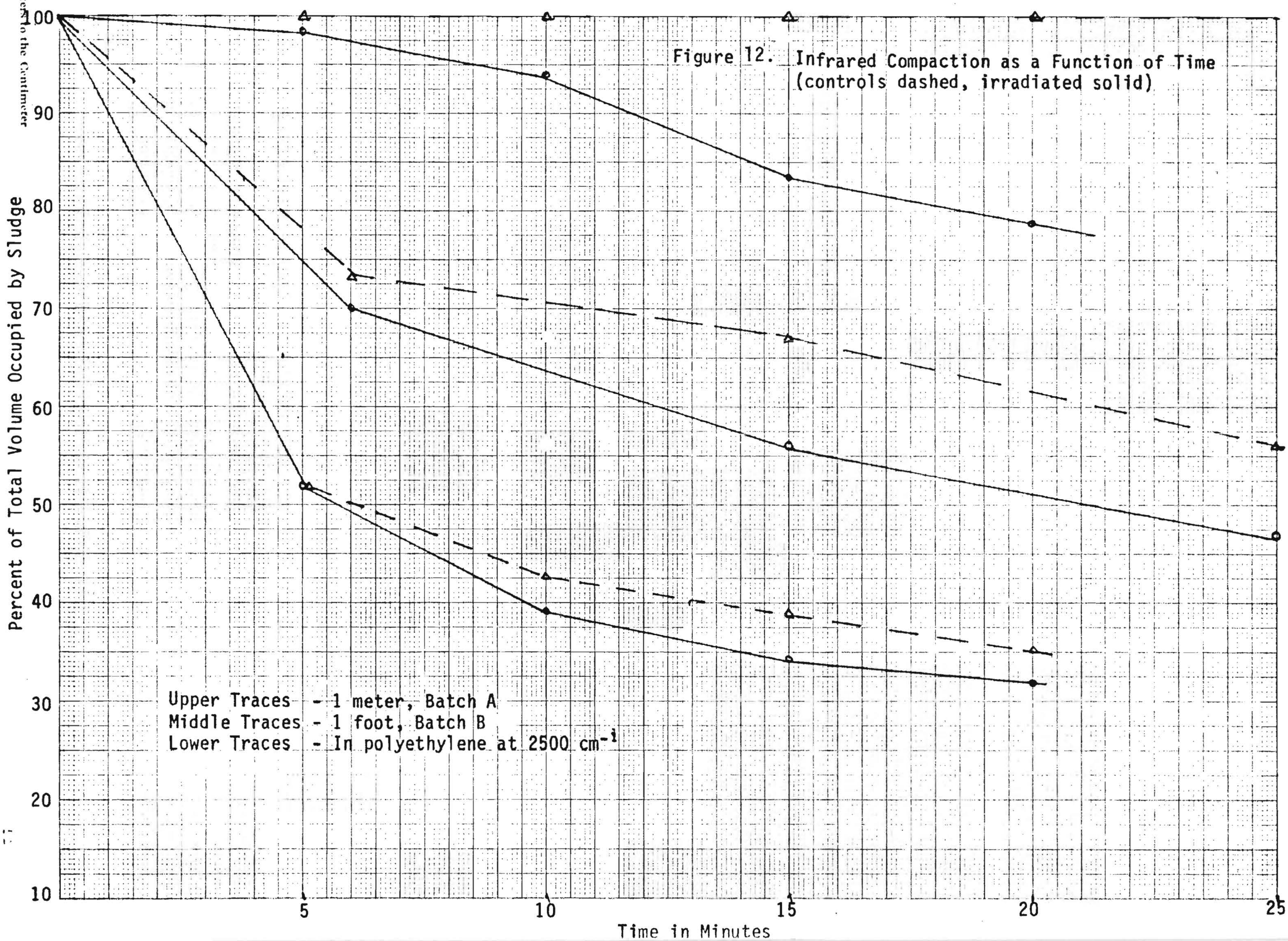


Figure 12. Infrared Compaction as a Function of Time
(controls dashed, irradiated solid)
Percent of Total Volume Occupied by Sludge
100
90
80
70
60
50
40
30
20
10
5
10
15
20
25
Time in Minutes
Upper Traces - 1 meter, Batch A
Middle Traces - 1 foot, Batch B
Lower Traces - In polyethylene at 2500 cm-1

BENCH STUDY - FILTERABILITY

This experiment was designed to determine whether or not differences in the filtration rates could be observed between irradiated sludge and sludge which had not been exposed to infrared radiation. A Buchner funnel was mounted on a filter flask which was, in turn, connected to a constant vacuum source. A disc of Watman No. 1 filter paper was moistened and placed in the funnel for each test. Precision was established by observing the time required to filter 450 ml of tap water. These results are outlined below.

Run	Time in Sec.
1	40
2	40
3	47
4	39
5	50
6	48
7	47
Mean	44.4
Standard Deviation	4.6
% Standard Deviation	±10

This degree of reproducibility was considered to be acceptable. Accordingly 450 ml portions of sludge were filtered. The times required to bring the visible film of water away from all but the outer ring of the filter cakes were recorded for both control and irradiated sludge as outlined on the next page.

Run	Control	Irradiated
1	13.2	17.2
2	14.2	13.2
3	12.5	11.5
4		17.5
Mean	13.3	14.9
Standard Deviation	0.85	3.0
% Standard Deviation	±6.4	±20.0

t = 0.89 for 5 degrees of freedom

Because the two means were not significantly different and because the temperatures of the irradiated sludges had not been controlled, a more rigorous experiment was devised in which the effects of both temperature and irradiation were considered. Measurements were made on the same day using the same batch of sludge (Macon, GA). A factorial design was employed with two levels in each factor being considered as shown below along with the times required for filtration in minutes.

	22° C.		38° C.	
	Lamp On	Lamp Off	Lamp On	Lamp Off
	4.75	4.37	4.0	5.5
	6.15	6.0	4.5	3.68
	5.5	5.17	4.0	5.2
	5.25	4.7	4.82	4.0
	5.17	4.87		
Means	5.36	5.02	4.33	4.59

These results were subjected to statistical analysis on Georgia Tech's CYBER 74 time-shared computer system using the SPSS ANOVA n-way

analysis of variance program. The results of this statistical treatment of the data, which are presented below show that no statistically significant effect of the irradiation alone was observed. On the other hand, a significant temperature effect (p = 0.027) was noted. The two-way interaction was not significant. The temperature effect is to be expected on theoretical grounds and therefore supports the overall validity of the experiment.

- - - ANOVA - - -

TIME
BY LAMP
TEMP

SOURCE OF VARIATION	SUM OF SQUARES	DF	MEAN SQUARE	F	SIGNIF OF F
MAIN EFFECTS	2.395	2	1.198	3.072	.078
LAMP	.023	1	.023	.060	.810
TEMP	2.372	1	2.372	6.084	.027
2-WAY INTERACTION	.409	1	.409	1.050	.323
LAMP TEMP	.409	1	.409	1.050	.323
EXPLAINED	2.805	3	.935	2.398	.112
RESIDUAL	5.457	14	.390		
TOTAL	8.262	17	.486		

18 CASES
0 MISSING (0 PCT)

The t-test data which are presented below include the means, standard deviations and standard errors for each of the cells. These results also support the conclusion that irradiation produced no significant changes while the elevated temperature produced a significant improvement in the filtration rate.

- - - T - TEST - - -

TIME

	GROUP 1 Lamp On	GROUP 2 Lamp Off
NO. OF CASES	9	9
MEAN	4.9044	4.8322
STD. DEV.	.7006	.7341
STD. ERROR	.2335	.2447
F-VALUE	1.10	
2-TAIL PROB.	.898	

	T-VALUE	DF	P-VALUE
POOLED VAR. EST.	.21	16	.834
SEPARATE VAR. EST.	.21	15.97	.834

- - - T - TEST - - -

TIME

	GROUP 1 22°C	GROUP 2 38°C
NO. OF CASES	10	8
MEAN	5.1930	4.4625
STD. DEV.	.5663	.6550
STD. ERROR	.1791	.2316
F-VALUE	1.34	
2-TAIL PROB.	.669	

	T-VALUE	DF	P-VALUE
POOLED VAR. EST.	2.54	16	.022
SEPARATE VAR. EST.	2.50	13.99	.026

SETTLING VS. WAVELENGTH

Preliminary tests designed to uncover a dependency of the compaction phenomenon upon the wavelength of the incident radiation were carried out in quartz UV - vis spectrophotometer cells. Unfortunately, these cells were transparent (80% T or better) only from 2800-3400 cm^{-1}. Some light was able to pass through the cells from 2100-3800 cm^{-1} (10% T or better), albeit with varying intensity. For this reason, nearly all of the observations made with this equipment must be regarded as inconclusive. The results described in our letter of April 19, 1978 are worthy of note, however, since the ratios of control to irradiated samples were found to be 1.3 at 2100 cm^{-1} and 2200 cm^{-1} and nearly unity at 2300, 2400 and 2700 cm^{-1} in spite of the fact that the cells are more transparent to infrared radiation at the less responsive wavelengths. Unfortunately, this difference, although still observed in subsequent repeated experiments was not nearly as dramatic and, in fact, was no longer sufficiently large to be considered statistically significant.

In an effort to overcome this difficulty, new cells were constructed first out of polystyrene and finally out of polyethylene. While both were found to have vastly improved transmission properties when compared to those exhibited by the quartz cells, the polyethylene showed only three narrow adsorption bands at 2900-3150, 1480-1530 and 760-780 cm^{-1} and was essentially transparent throughout the rest of the range of the spectrophotometer. Since polystyrene had a number of other bands in addition to these three, all subsequent work has been carried out with the polyethylene.

While experiments in this area did not reach any strong conclusions it was apparent that irradiation for 15-20 minutes shows an effect at 2200 and 2300 cm^{-1} but not at 2500 cm^{-1}. The observed ratios of control to irradiated samples were 1.2, 1.1 and 1.0 respectively. This evidence agrees with that reported earlier. Temperatures were not recorded. In order to more conclusively resolve this issue, a more intensive variable wavelength light source would be required. The investigators did not believe that the procurement of such a source would produce sufficient information to justify the investment.

MEMORY EFFECT

If the infrared-induced compaction involves a redistribution of surface charges as has been speculated in earlier reports, it would seem unlikely that such an effect would be totally reversible. While early results had indicated that a very high degree of reversibility was characteristic of the phenomenon, a quantitative assessment of this observation was not undertaken until the current reporting period. A sample of sludge from the Macon facility was placed in a 100 ml graduate and subjected to infrared radiation in the usual manner. After 10 minutes of irradiation, the ratio of percent settling in the control to that of the irradiated sample was 2.9. The two samples were then resuspended and allowed to resettle. The ratio recorded after 4 minutes was 1.4 thus demonstrating that the effect is only partly reversible.

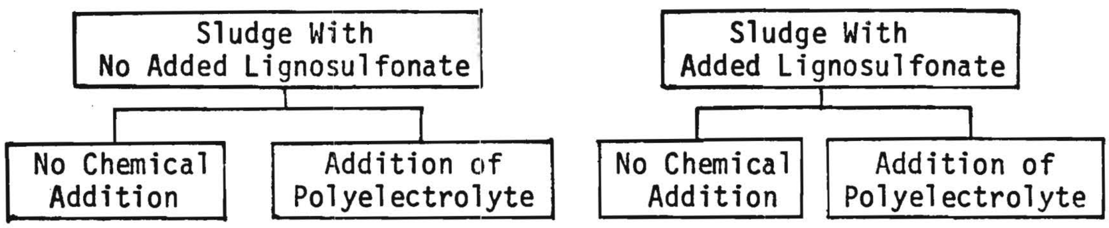
EFFECT OF pH, SALT, DETERGENT AND SOLVENT EXTRACTION

Changing the pH to 4 and 9 did not alter the degree of response to infrared radiation. Adding a sufficient amount of sodium chloride to make the resulting mixture 1% in NaCl did not alter the IR response, although the change in density was sufficient to cause the IR-compacted sludge to float instead of sink.

Adding a very large amount of anionic detergent (enough to make the final solution 1%) changed the appearance of the IR-induced compaction in that the agglommerating floc particles seemed larger and smoother but did not appear to change their rate of settling. Hexane and ethyl acetate extractions introduced complicating factors in that solvent residuals subsequently caused the compacting sludge to float. Nevertheless it was possible to conclude that the IR activity was not being extracted away.

EFFECT OF LIGNOSULFONATE AND ADDED POLYELECTROLYTES
ON ORDINARY ACTIVATED SLUDGE

This section describes the series of experiments outlined in Item 3 of our letter of March 16, 1978. The experimental design is presented below.



As described briefly in our letter of July 10, 1978, this experiment produced some very interesting results in that the untreated samples showed a strong response to the infrared radiation. Furthermore, the results of polyelectrolyte addition were much more dramatic than had been anticipated. It will be noted that a cationic, non-quaternary polyelectrolyte (Purifloc C-31, Dow) was used in place of the Chitosan. This substitution was made on the basis of solubility considerations. In retrospect, Chitosan would probably have performed as well.

The compositions of the test mixtures are summarized below:

1) No chemical addition, Bolton Sludge, 2 liters
2) No. 1 plus 15 ml of a 1% solution of Purifloc C-31
3) No. 1 plus 40 ml of 1% lignosulfonate solution
4) No. 1 plus 15 ml of Purifloc plus 40 ml lignosulfonate

The mixtures were aerated and fed irregularly with 25 ml of a solution containing 24 g dextrose, 5.0 g glycine and 800 mg disodium hydrogen phosphate per liter. The type of food and feeding schedule were designed to encourage bulking. The addition of reagents was begun as

Visual inspection indicated the heavy involvement of filamentous organisms after 24 hours, thus making the last series of observations somewhat questionable. The added lignosulfonate increased the degree of bulking about 10% and may have decreased the measured ratios somewhat. A statistical analysis was performed on the data in an effort to resolve these and other questions. Georgia Tech's CYBER 74 multiprocessor computer system was used in combination with the SPSS software to perform an analysis of variance and t-tests on the data presented in Table 2 . The results of this work are presented below.

- - - ANOVA - - -

RATIO
BY POLY
LIGNO
TIME

SOURCE OF VARIATION	SUM OF SQUARES	DF	MEAN SQUARE	F	SIGNIF OF F
MAIN EFFECTS	2.350	4	.588	10.095	.001
POLY	.294	1	.294	5.060	.037
LIGNO	.042	1	.042	.719	.407
TIME	2.128	2	1.064	18.283	.001
2-WAY INTERACTION	.210	5	.042	.723	.615
POLY LIGNO	.054	1	.054	.930	.347
POLY TIME	.032	2	.016	.272	.764
LIGNO TIME	.138	2	.069	1.184	.328
3-WAY INTERACTION	.158	2	.079	1.361	.280
POLY LIGNO TIME	.158	2	.079	1.361	.280
EXPLAINED	2.719	11	.247	4.247	.003
RESIDUAL	1.106	19	.058		
TOTAL	3.825	30	.127		

31 CASES
0 MISSING (0 PCT)

The interpretation of the above results is that the effect of added POLYelectrolyte is significant (0.037). The true significance is probably greater than shown on account of the fact that the degree of settling produced by the polyelectrolyte was tenfold greater than that which was observed in its absence. Thus when these samples were subjected to infrared light it was very difficult to establish ratios. It is probably more accurate to say that the polyelectrolyte produced dramatic changes in the settling characteristics of the sludge, regardless of whether or not it was subsequently exposed to infrared light. The influence of the added LIGNOsulfonate on the compaction ratios is not highly significant (0.407). In this case, the ease of measurement and number of comparisons are in better balance so that it is safe to say that the sludge responded to the infrared light in about the same way whether or not the lignosulfonate was present. Time was the most significant factor (0.001). Thus it is virtually certain that the length of time which the bulking has existed has the strongest influence on whether or not the sludge will respond to infrared light. This is probably related to the physical/chemical properties of the sludge and may explain why not all sludges respond equally to IR light. The T-test shown on the next page is supportive of the ANOVA conclusion regarding the effect of the polyelectrolyte. However, it is not significant in itself. The means and standard deviations are presented as a part of this data.

The next T-test examined the effect of lignosulfonate on the compaction ratios and like the ANOVA data was not statistically significant. The printout is presented on the next page.

- - - T - TEST - - -

RATIO

	GROUP 1 NO POLY	GROUP 2 WITH POLY
NO.OF CASES	23	8
MEAN	1.3874	1.2250
STD. DEV.	.3157	.4590
STD. ERROR	.0658	.1623
F-VALUE	2.11	
2-TAIL PROB.	.170	

	T-VALUE	DF	P-VALUE
POOLED VAR. EST.	1.11	29	.275
SEPARATE VAR. EST.	.93	9.41	.378

- - - T - TEST - - -

RATIO

	GROUP 1 NO LIGNO	GROUP 2 WITH LIGNO
NO.OF CASES	16	15
MEAN	1.3912	1.2967
STD. DEV.	.4147	.2898
STD. ERROR	.1037	.0748
F-VALUE	2.05	
2-TAIL PROB.	.188	

	T-VALUE	DF	P-VALUE
POOLED VAR. EST.	.73	29	.470
SEPARATE VAR. EST.	.74	26.88	.466

Mr. Poythress reports attempting to use polyelectrolytes to enhance settling characteristics both on the bench and in the Rocky Creek facility itself. Cationics are effective 90% of the time and when they don't work, anionics do. The sludges remained biologically effective. In-plant use was not successful however, due largely to mixing problems.

INDUCTION OF THE COMPACTION PHENOMENON IN ORDINARY ACTIVATED SLUDGES

In an effort to establish the general occurrence and hence the general utility of the phenomenon, activated wastewater sludges from Atlanta's Bolton, Utoy Creek, Clayton, Flint River and South River wastewater treatment facilities were brought to the laboratory and dosed with a carbohydrate-rich synthetic food mixture in order to induce bulking. No other chemical additions were made in this series of experiments. After periods of time ranging from 1 to 3 days, bulking was observed in all but the South River samples. Filamentous organisms did not appear to be dominant when bulking first occurred, but their numbers increased as the experiments continued. The response ratio was measured by comparing the volumes occupied by unsettled sludge in 10 ml graduated cylinders placed 50 cm from the infrared source and irradiated for 15 minutes with the volumes of unsettled sludge in 10 ml graduates which had not been exposed to the light. The results of these tests are summarized in Table 3. These results were quite exciting at the time and seemed to indicate that the phenomenon was not an isolated occurrence and was, in fact, rather common. The authors' natural conservatism, however, suggested taking a temperature profile of the sludges as they responded to the radiation. This work is described in the next section.

Table 3

Induction of IR-Compaction in Wastewater Sludges*

Source	1st Run	2nd Run	3rd Run	4th Run
Bolton	1.47	1.71	1.49	
Utoy Creek	1.47	1.37	1.31	
Clayton	0.99	1.00		
Flint River	1.12	1.10	1.13	
South River	Near 1.00	-	-	
Utoy Creek (later date)	1.37	1.19	1.12	1.40
Concentrate of Above	1.42	1.51	1.54	1.52

*Ratios = $\frac{\text{volume control sludge}}{\text{volume irradiated sludge}}$

EFFECT OF HEAT

In connection with our experiments designed to induce the compaction phenomenon in other bulking sludges, a series of experiments was designed to investigate the effect of heat alone on the compaction of bulking sludges. Since work predating the award of the contract had shown no heat effect, it was most disconcerting to note that the very first attempt to produce a heat-induced compaction which was performed on a sample of IR-active Macon sludge showed a degree and type of compaction which was exactly like that which had been observed with the infrared lamp. The effects were so much alike that it was not possible for an independent observer to distinguish which means had been used to produce the phenomenon. An examination of the behavior of locally obtained sludges into which the bulking phenomenon had been induced when heated to 70°C in a hot water bath produced the results shown in Table 4. All samples were placed in 10 ml graduated cylinders exposed for 15 minutes after which time the volumes occupied by the sludges were compared with those of equal amounts of sludge which had been kept at room temperature for the same length of time. These results expressed as $\frac{\text{volume control sludge}}{\text{volume exposed sludge}}$ confirmed that the effect of this amout of heat was at least equal to the effect of the infrared radiation.

Detailed qualitative observations regarding the rate of temperature climb and the appearance of the sludge (Macon) with time during exposure to heat alone (hot water) and infrared radiation in separate tests again led to the conclusion that no obvious differences could be found between

Table 4

Effect of Heat Upon Compaction of Sewage Sludge

Source	Run 1	Run 2	Run 3
Utoy Creek	3.00	2.78	2.86
Flint River	1.28	1.16	
South River	1.17	1.43	1.33
Clayton	2.91	3.21	2.59
Macon	2.37		

the compactions induced by either mechanism. The final ratios were exactly the same.

In an effort to find at least one differentiating feature, the two compacted sludges were resuspended and allowed to resettle. Much to the experimenter's surprise, the infrared-compacted sludge exhibited the "memory" effect previously observed while the heat-compacted sludge immediately showed a weaker memory effect. This difference persisted throughout the three-hour observation period. The final ratios of control to exposed were 1.93 and 1.70 respectively. These observations suggested that further experimentation might yet succeed in separating the IR effect from the heat effect.

ISOLATING THE EFFECTS OF TEMPERATURE AND INFRARED RADIATION

As soon as the magnitude of the heat-induced compaction began to be appreciated, the authors sought to coneive of an experimental design which could isolate the two effects. A simple plan for maintaining a constant temperature during irradiation involved sheathing the graduated cylinder which was being irradiated in a stream of flowing water. Hopefully a thermal equilibrium would be established at a temperature which was not very different from that of the water itself. Preliminary experiments established that temperatures in the range of 27-30^{o}C (depending on the flow rate of the water) could be maintained using Atlanta tap water.

A series of experiments was set up on the basis of this information in which samples of sludge (50 ml) were irradiated at a distance of 20 cm for 15 minutes while encircled by a sheath of running water which was flowing at such a rate as to maintain the temperature at 28^{o}C. Comparison samples were immersed in a water bath away from the light at 28^{o}C while still other samples were held in the dark at room temperature (22^{o}C). A comparison of the sludge volumes in the 22^{o} controls with those in the irradiated samples provides an estimate of the degree of response due to both heat and light. A similar comparison of the compacted sludge volumes in the control at 28^{o}C and the infrared-exposed samples at 28^{o}C isolates the effect of light. A final comparison between the non-irradiated sludge volumes at 22^{o}C and at 28^{o}C provides a measure of the degree of response due to heat alone. The results of eight replicate tests are presented in Table 5.

Table 5

Effects of Temperature and Infrared Radiation

Run No.	Volume of Control at 22°C / Volume of IR at 28°C	Volume of Control at 28°C / Volume of IR at 28°C	Volume of Control at 22°C / Volume of Control at 28°C
1	1.37	1.36	1.01
2	1.21	1.08	1.12
3	1.27	1.12	1.14
4	1.20	1.13	1.04
5	1.24	1.22	1.02
6	1.43	1.43	1.01
7	1.09	1.07	1.02
8	1.17	1.07	1.09

A statistical analysis of the data was performed using the T-test in order to help answer the following questions:

1. Is the degree of response to heat and infrared light together significantly different from that due to IR alone? A comparison of Columns 1 and 2 provides an estimate. The statistical evidence ($t = 3.02$, $p < 0.01$) indicates that there is a highly significant difference between the response to both factors and the response to IR alone. Thus the effect of heat cannot be ignored.
2. Is the degree of response to both heat and infrared light significantly different from that due to heat alone? In this case a comparison of Columns 1 and 3 provides the estimate ($t = 4.07$, $p < 0.005$). This means that there is a very highly significant difference between the degree of response to both factors and the response to heat alone. Thus the effect of IR cannot be ignored either.

3. Is the magnitude of the heat effect significantly different from that of the IR effect? A comparison of Columns 2 and 3 provides the required information ($t = 2.06$, p 0.07). While the level of significance is not as large as was seen in the first two cases, there is still a significant difference.

Subsequent experiments with other batches of sludge have produced similar results. It has been noted that the differences between the factors is dependent upon the nature of that particular sludge, upon the temperature differential and upon the intensity of the irradiation. Qualitatively, it has been found that the temperature differential must be at least 5^{o}C in order to produce an effect which can be statistically verified. Similarly, the intensity of the light and the nature of the sludge should be such that at least a 30% reduction in the volume can be brought about by irradiation. This general information was applied to related experiments designed to assess the relative importance of irradiation and heat on a variety of wastewater sludges. These results indicate that upon the inducement of bulking and prior to the over development of filamentous organisms, the infrared compaction phenomenon as observed in carefully controlled experiments of this type is a generally occurring phenomenon. The effect is transitory however, and only partly due to the light alone and therefore, would seem to have little practical utility if an artificial means of applying the radiation were to be employed. Judiciously positioned solar reflectors in some kind of holding basin might however, improve settling, and handling characteristics to a degree which might permit a very modest investment to be made. These results have already been described in greater detail in an earlier section.

CONCLUSIONS

Infrared radiation in combination with heat has a compacting effect on bulking wastewater sludges in general. The significance of the infrared portion of this activity has been statistically established using sludge from Macon's Rocky Creek facility. This facility treats a mixture of pulp-mill waste and domestic waste and it would appear that the pulp-mill contribution, in addition to creating the bulking in the first place, was responsible for making the IR response so dramatic as to have been instantly recognizable during the pilot study period. Since the personnel at this facility are now familiar with the compaction phenomenon, it continues to be observed in spite of being considerably less dramatic than before. The portion of the effect which is due to infrared radiation alone has been reduced to the point at which repeated observations and statistical methods are necessary to recognize the contribution of this component at all. Studies with other wastewater sludges in which bulking has been induced by an alteration of the feed have shown that an infrared-sensitive stage may be part of the development of bulking in general which is shortly thereafter characterized by an over-abundance of filamentous organisms.

Mr. Poythress' studies at Macon involving the deliberate addition of polyelectrolytes to the working sludge coupled with our own bench studies in Atlanta suggest that an entirely new wastewater treatment process based on the maintenance of a cationic aeration/treatment basin in addition to the conventional basins would concievably result in tremendous advantages in handling costs if the cationic and anionic (conventional) streams were mixed prior to final setting and dewatering. Such work would appear to be an appropriate topic for future research.

FINAL REPORT

EFFECT OF INFRARED RADIATION ON COMPACTION OF MUNICIPAL WASTEWATER SLUDGES

NSF GRANT ENV 77–15086

Dr. R. S. Ingols and Dr. S. C. Havlicek
Mr. M. H. Poythress and Mr. J. D. Lupton

GEORGIA INSTITUTE OF TECHNOLOGY
SCHOOL OF CIVIL ENGINEERING
ATLANTA, GEORGIA 30332

1979

FINAL REPORT

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Washington, D.C. 20550 SUMMARY OF COMPLETED PROJECT OMB No. 99R0013

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INSTITUTION AND ADDRESS		2. NSF PROGRAM	3. GRANT PERIOD
orgia Institute of Technology lanta, Georgia 30332		Community Water Management	18 months from 7/1/77 to 12/31/78
GRANT NUMBER	5. BUDGET DUR. (MOS)	6. PRINCIPAL INVESTIGATOR(S)	7. GRANTEE ACCOUNT NUMBER
V77-15086	18 mon.	Dr. S. C. Havlicek	B-491-000

SUMMARY (Attach list of publications to form)

The success of the activated sludge process commonly used for the treatment of waste-ters depends upon the separation of solids in the secondary sedimentation tank and on their concentration for internal recycling. Therefore poorly settling (bulking) udges are one of the chief causes of difficulty with the process. The research under-ken in connection with this project was concerned with the study of an unusually strong frared-induced compaction of poorly settling sludges observed at Macon GA's Rocky eek wastewater treatment facility. In attempting to study the phenomenon, it was noted at the degree of settling induced by infrared radiation at Macon was not as pronounced it had been in the past. In spite of this difficulty, it was discovered that the enomenon has two components - that which is induced by heat alone and that which is luced by the irradiation alone. Furthermore, the phenomenon is generally observed in orly settling sludges during the early stages of bulking. It is not present during e later stages of ordinary bulking when the overgrowth of filamentous organisms ef-ctively blocks compaction.

Since the effects produced by the infrared radiation as genrally observed are small, did not seem to be worthwhile to continue with the originally planned larger scale se II studies. The transfer of funds set aside by NSF for these studies was therefore requested

Other finds were as follows: (1) IR wavelengths of 2200-2300 cm^{-1} seemed to be the most ective (2) Irradiated sludge, when resuspended, settled better than untreated sludge Added polyelectrolytes vastly improved settling regardless of irradiation (4) Ligno-fonate, a major constituent of pulpmill wastes, had little effect on the phenomenon.

In spite of the largely negative findings, the study did suggest that the use of -cost infrared radiation in the form of reflected solar energy might have a favorable ect upon the settling of activated sludges. Part of this beneficial action would due to the improved handling characteristics caused by an increase in temperature.

SNATURE OF PRINCIPAL INVESTIGATOR/ OJECT DIRECTOR	TYPED OR PRINTED NAME	DATE
Stephen C Havlicek	Stephen C. Havlicek	3/24/79

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DISCLAIMER

The information contained in this document is based upon research supported by the National Science Foundation under Grant No. ENV77-15086. Any opinions, findings and conclusions or recommendations expressed in this publication are those of the authors and do not necessarily reflect the views of the National Science Foundation.

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EXECUTIVE SUMMARY

The activated sludge process is widely employed for the treatment of wastewaters from both domestic, industrial and mixed sources. The success of this treatment is dependent upon the separation of solids in the secondary sedimentation tank and upon their concentration for subsequent return to the aeration tank. Therefore, it is not surprising that bulking (poorly settling) sludges exacerbate difficult disposal problems which are already one of the major headaches associated with wastewater treatment. It would thus seem worthwhile to explore any process which had the possibility of reducing the extra load of waste sludge caused by bulking conditions or which could bring about compaction of wastewater sludges in general. New methods of sludge debulking which do not involve the use of chlorine are particularly interesting since it has already been established that this practice, while effective, leads to the production of potentially hazardous chloroorganic materials.

Since the authors had noted the occurrence of an unusual infrared-induced sludge compaction phenomenon which took place at Macon, Georgia's Rocky Creek wastewater treatment facility, a research program was proposed to and subsequently funded by the National Science Foundation to investigate the nature of the phenomenon in the hope that a method for making the IR-enhanced settling generally applicable could be demonstrated.

Since the original studies performed in connection with the design and monitoring of a pilot wastewater treatment facility at Macon, Georgia, which are summarized in the first section of this report, the relative proportions of the waste streams and their characteristics have been in a state of constant change. The compaction phenomenon as observed during the operation of our own mini-pilot facility was not nearly as pronounced as it had been in earlier years. It is, however, still recognizable. Upon the evaluation of the results of these studies and as an outgrowth of the bench testing work conducted in the Experiment Station's own laboratories, the Principal Investigators were forced to conclude that a continued investigation of ways to apply the phenomenon to the improvement of bulking sludges in general did not seem to warrant carrying out the Phase II studies outlined in the original proposal. The factor responsible for the dramatic nature of the phonemenon at Macon appears to be associated with the pulpmill wastes which are also responsible for inducing the bulking in the first place. Although the 1R phonomenon can be induced in ordinary activated sludge as a result of deliberately altering the feed, it appears to be a transient occurrence which preceeds the onset of true filamentous bulking. The performance of this work fulfilled the original objectives of the Phase I studies. Additional studies have been carried out to further strengthen these conclusions and provide new leads for further studies of a somewhat different nature.

A factorial experiment was designed to investigate the effect of temperature and irradiation on the filterability of the sludge. As expected, there was a significant improvement in filterability at the warmer temperatures. There was no significant difference which could be attributed to the irradiation. It might be noted however, that application of this well-established effect might be generally helpful in wastewater treatment if very low cost heat were employed to elevate the temperature of wastewater sludges prior to dewatering, i.e.; solar energy or waste heat.

Studies aimed at defining the wavelength of maximum response were performed on a conventional infrared spectrophotometer and hinted at a maximum response at 2200 cm^{-1} and 2300 cm^{-1}. This evidence however, did not prove to be statistically significant and would have to be reexamined using a more intense variable wavelength source. If substantiated, these observations could be of fundamental importance as there are not many characteristic IR bands in this region.

There was a memory effect in that irradiated sludge when resuspended still settled better than untreated sludge. Thus, the changes produced by irradiation are only partially reversible. Changes in pH, salt concentration, the addition of an anionic detergent and solvent extractions did not appear to alter the response.

A factorial study with added lignosulfonate and added polyelectrolytes on ordinary activated sludge under conditions designed to induce bulking showed that the effect of added polyelectrolyte was highly significant in that vastly improved settling characteristics were produced regardless of whether or not the treated sludge was subsequently exposed to infrared light. The addition of lignosulfonate did not significantly alter the response to the infrared radiation. This finding was quite surprising to the principal investigators since we had originally presumed the lignosulfonate component of the pulp mill wastes to be involved either in the absorption of the infrared radiation or in the creation of excess anionic charge on the surface of the bulking sludge particles. Now it would seem that perhaps the presence of wood sugars or some other component of the pulp mill wastes may be upsetting the ability of the biological system to produce a normal sludge. The fact that the length of time which the bulking has existed has the strongest influence on whether or not the sludge will respond to infrared-radiation suggest that an infrared-responding stage may be part of the normal course of events when an activated sludge wastewater treatment process is subjected to stresses ultimately resulting in filamentous bulking. This conclusion has been supported by other experiments in which the IR phenomenon was successfully induced in a variety of municipal sludges.

Experiments performed at Macon have demonstrated that polyelectrolytes do enhance the settling characteristics of activated sludges and that, if added at an early stage, do not interfere with the biological effectiveness of the system. In-plant use was not successful however, due largely to mixing problems.

Another series of experiments was performed which demonstrated that heat alone was capable of producing a compacting effect which was very similar to that observed with the infrared radiation alone. The only differentiating feature was the stronger memory effect exhibited by the irradiated sludge. A series of experiments were performed in an effort to statistically isolate the effects of heat and exposure to infrared irradiation. The results of these experiments indicate that both effects are statistically significant and that they are different from each other.

These experiments are described in greater detail in the sections which follow.

EARLIER STUDIES AT MACON

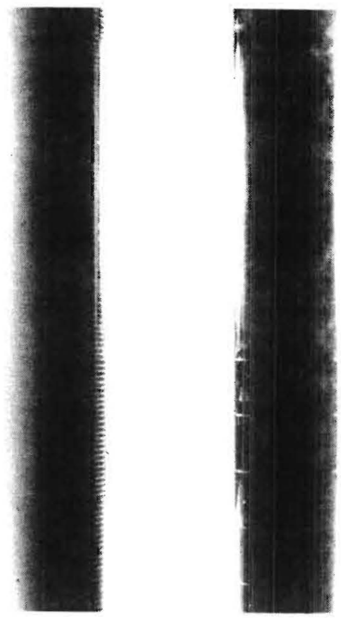
In 1969, two of the three principal investigators participated in the design and monitoring of a pilot wastewater treatment facility at Macon, Georgia. During this study period in which two variations of a typical activated sludge process were employed to stabilize the mixed wastes from a manufacturing plant (Armstrong Cork), a pulp mill (Georgia Kraft), and a municipal component, bulking was a continuous problem. As the tests progressed it was noted that the type of bulking responsible for the poor settling characteristics of the treated wastewaters did not appear to involve an overgrowth of filamentous organisms as is typically the case. Furthermore, it was noted that the bulky sludge rapidly compacted if exposed to sunlight while companion samples shielded from the light retained their bulking characteristics. An example of these differences is shown in Figure 1. At this time, the input to the pilot facility was composed of the following contributions from the three sources indicated below:

Armstrong Crok............20%

Georgia Kraft.............60%

Municipal.................20%

The characteristics of the input stream are outlined in Table I, and presented graphically in Figures 2 through 9. Since that time, a full scale facility has been placed in operation at Macon. The bulking problem remains. The input stream characteristics have changed somewhat with Armstrong Cork choosing to treat its own wastes separately. The proportional contribution from the pulp mill has decreased as water recycling and in-plant recovery of



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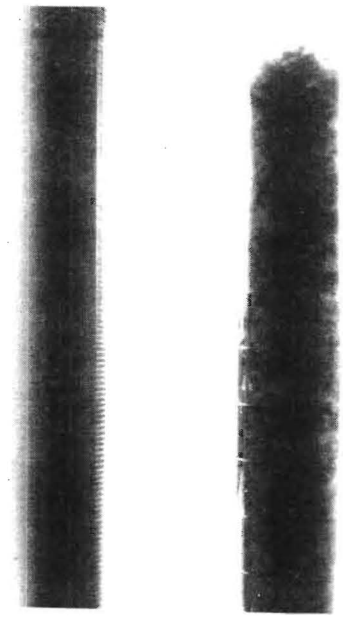
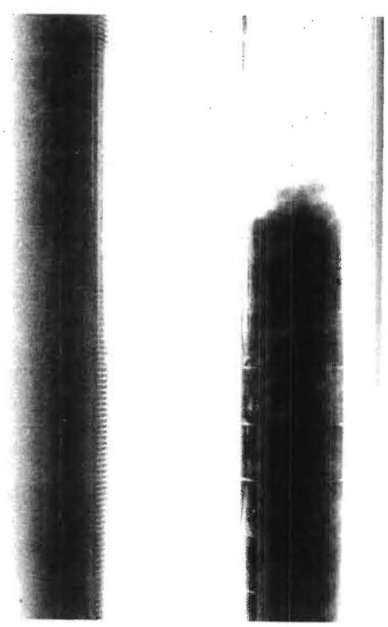


10 Minutes



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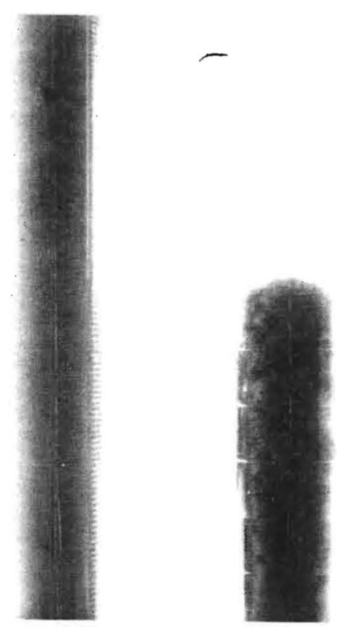


30 Minutes

Input Stream Characteristics During Pilot Study Period*

		Armstrong Cork (20%)		Georgia Kraft (60%)		Municipal at Pio Nono Outfall (20%)	
Property Measured	Month	Range	Average	Range	Average	Range	Average
pH	April	5.7-7.1	6.4	8.9-10.0	8.4	7.0-7.3	7.2
	May	6.2-7.7	6.8	7.0-10.2	9.9	6.8-7.2	7.1
	June	6.0-7.0	6.6	9.7-10.4	10.1	7.0-7.5	7.2
	July	6.8-7.2	6.9	8.6-9.9	9.7	7.1-7.6	7.3
	Aug.	NA	NA	9.8-10.2	10.0	7.2-7.7	7.5
	Sept.	NA	NA	9.1-9.8	9.4	7.2-7.7	7.4
	Oct.	5.9-7.3	6.7	9.5-10.4	10.0	7.3-7.7	7.5
	Nov.	5.7-7.1	6.3	7.8-10.4	9.6	7.2-7.7	7.5
	Dec.	6.1-6.8	6.3	NA	NA	7.5-7.6	7.6
Total Solids (mg/l)	April	3046-6482	4365	794-1078	892	282-540	436
	May	3360-4308	3839	680-1294	963	354-714	550
	June	2098-4908	3844	742-1346	1019	478-1020	643
	July	2420-4904	3624	702-1364	1153	474-726	590
	Aug.	NA	NA	880-1150	1040	155-722	506
	Sept.	NA	NA	705-1000	879	350-790	617
	Oct.	3830-9840	6038	890-1545	1124	480-685	561
	Nov.	2660-8820	4299	570-2130	1460	450-680	561
	Dec.	3820-6000	4783	NA	NA	540-620	571

*1970 - We are grateful fo the City of Macon for supplying these data.

Input Stream

Property Measured -	Month	Range	Average	Range	Average	Range	Average
Total Volatile Solids	April	2462-5126	3252	364-702	511	160-448	228
	May	2170-2740	2580	286-670	453	156-492	420
	June	1180-3902	2672	420-678	525	288-482	355
	July	1450-2810	2315	378-754	601	268-380	325
	Aug.	NA	NA	360-535	409	150-482	280
	Sept.	NA	NA	165-310	253	120-415	276
	Oct.	3015-5855	4093	200-690	404	205-400	306
	Nov.	1845-6400	3061	385-870	578	200-410	319
	Dec.	2960-4970	3738	NA	NA	220-340	275
Suspended Solids - (mg/l)	April	1530-3915	2163	53-285	165	105-228	178
	May	1370-2330	1727	45-280	161	45-350	215
	June	760-2480	1628	10-140	92	100-275	202
	July	980-2310	1700	35-155	83	55-275	196
	Aug.	NA	NA	95-150	123	105-210	157
	Sept.	NA	NA	25-76	59	100-205	172
	Oct.	1240-6920	3170	40-140	89	140-240	187
	Nov.	980-3860	2091	80-555	205	80-330	186
	Dec.	2190-4490	3063	NA	NA	180-365	226

TABLE 1 (Continued)

Volatile Suspended - Solids (mg/l)	Month	Range	Average	Range	Average	Range	Average
	April	NA	3235	NA	53	NA	113
	May	1020-1530	1275	NA	NA	NA	70
	June	920-1820	1262	0-100	50	110-210	160
	July	1080-2310	1610	15-65	34	30-230	140
	Aug.	NA	NA	NA	NA	NA	NA
	Sept.	NA	NA	NA	70	NA	70
	Oct.	1120-4740	2160	10-78	34	90-170	123
	Nov.	820-2440	1411	40-280	132	65-300	150
	Dec.	1630-2930	2225	NA	NA	110-165	126

Settleable Solids - (ml/l/hr)	Month	Range	Average	Range	Average	Range	Average
	April	80-140	107	2.0-2.5	5.5	6.5-9.0	7.7
	May	30-100	65	0.8-26	4.7	2.5-16	9.7
	June	9-130	86	0.9-2.5	1.8	4.5-17	7.7
	July	30-120	80	0.6-9.0	2.6	6.5-10	7.4
	Aug.	NA	NA	0.5-2.5	1.6	5.0-9.0	7.5
	Sept.	NA	NA	0.8-2.0	1.5	4.5-9.0	7.0
	Oct.	50-180	120	0.1-1.5	0.7	5.5-9.5	7.8
	Nov.	50-140	79	0.7-14	7.3	8.0-10	9.2
	Dec.	80-120	98	NA	NA	7.5-10	9.1

TABLE 1 (Continued)

	Month	Range	Average	Range	Average	Range	Average
BOD (20°C, 5 day) - (mg/l)	April	1150-1950	1558	260-460	378	160-200	184
	May	800-1700	1384	180-500	342	140-260	191
	June	950-2150	1736	160-580	390	150-320	233
	July	1050-2000	1450	220-500	380	130-290	190
	Aug.	NA	NA	380-760	450	150-200	180
	Sept.	NA	NA	380-440	400	160-220	192
	Oct.	1400-2100	1800	310-580	410	160-240	190
	Nov.	850-1650	1185	200-520	341	160-250	218
	Dec.	1100-1650	1375	NA	NA	180-280	237
COD (mg/l)	April	3500-5380	4102	760-1170	923	360-480	391
	May	2450-4570	3637	480-1300	916	210-480	377
	June	2960-4130	3576	340-1200	905	290-1020	455
	July	2420-6050	3680	560-2000	1170	280-410	370
	Aug.	NA	NA	910-1690	1096	300-410	375
	Sept.	NA	NA	870-1340	1012	380-420	400
	Oct.	4080-10320	6380	910-1380	1080	360-480	400
	Nov.	2760-8720	4245	370-2190	1359	320-450	386
	Dec.	4480-6200	5160	NA	NA	400-640	507

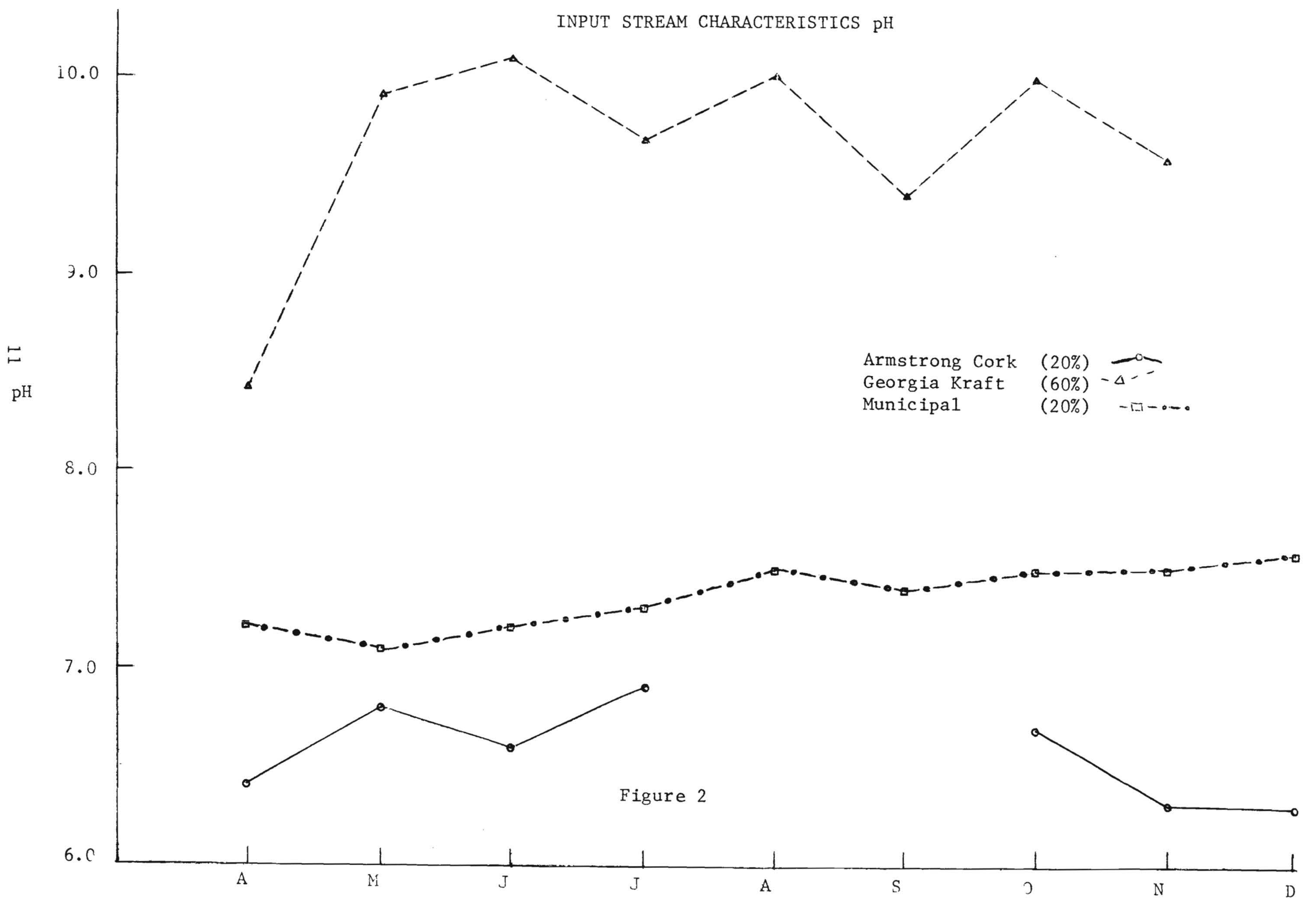

INPUT STREAM CHARACTERISTICS pH
10.0
9.0
8.0
7.0
6.0
pH
Armstrong Cork (20%)
Georgia Kraft (60%)
Municipal (20%)
A
M
J
J
A
S
O
N
D

Figure 2

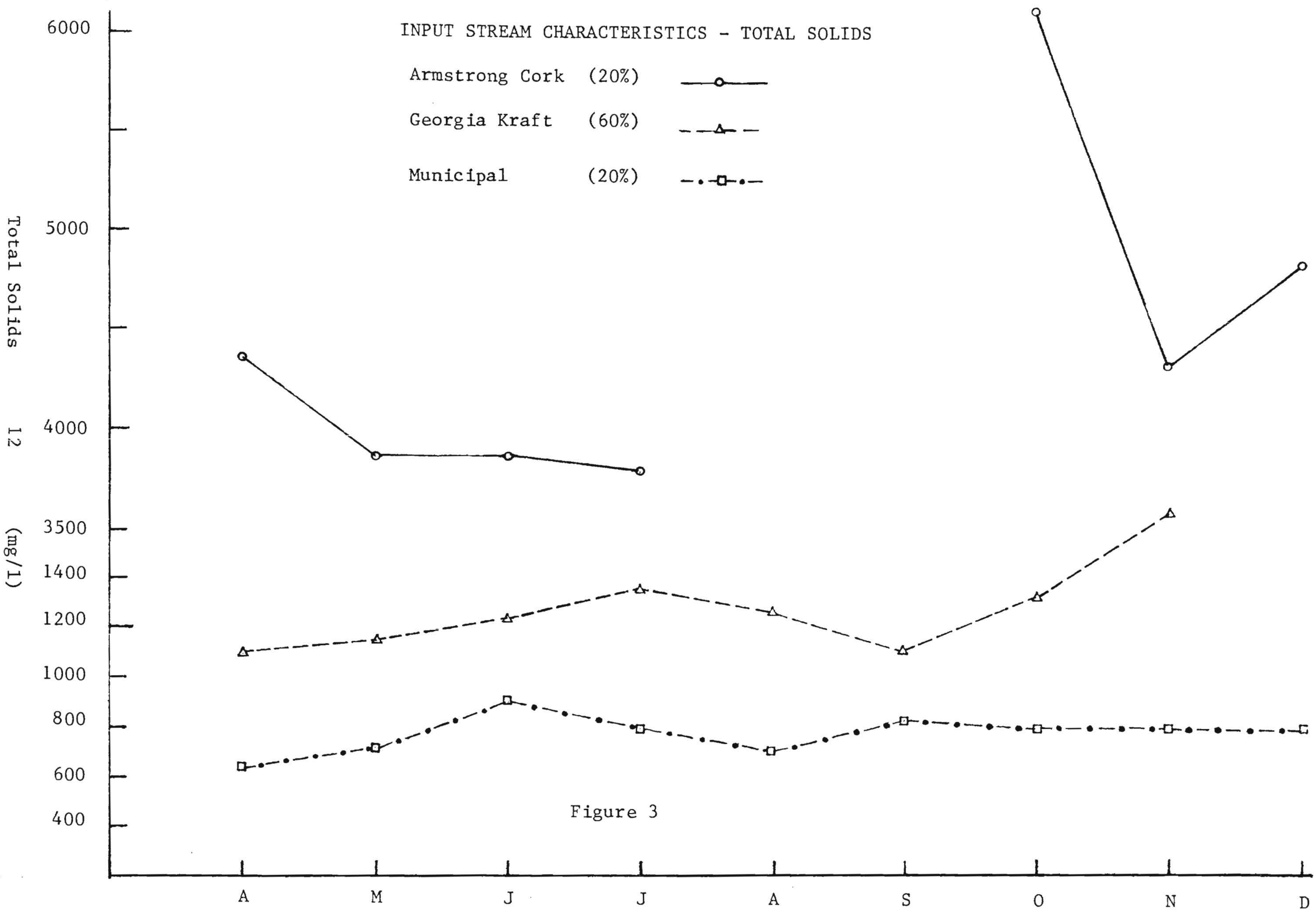

INPUT STREAM CHARACTERISTICS - TOTAL SOLIDS
Armstrong Cork (20%)
Georgia Kraft (60%)
Municipal (20%)
Total Solids
12
(mg/l)
6000
5000
4000
3500
1400
1200
1000
800
600
400
A
M
J
J
A
S
O
N
D

Figure 3

INPUT STREAM CHARACTERISTICS - TOTAL VOLATILE SOLIDS

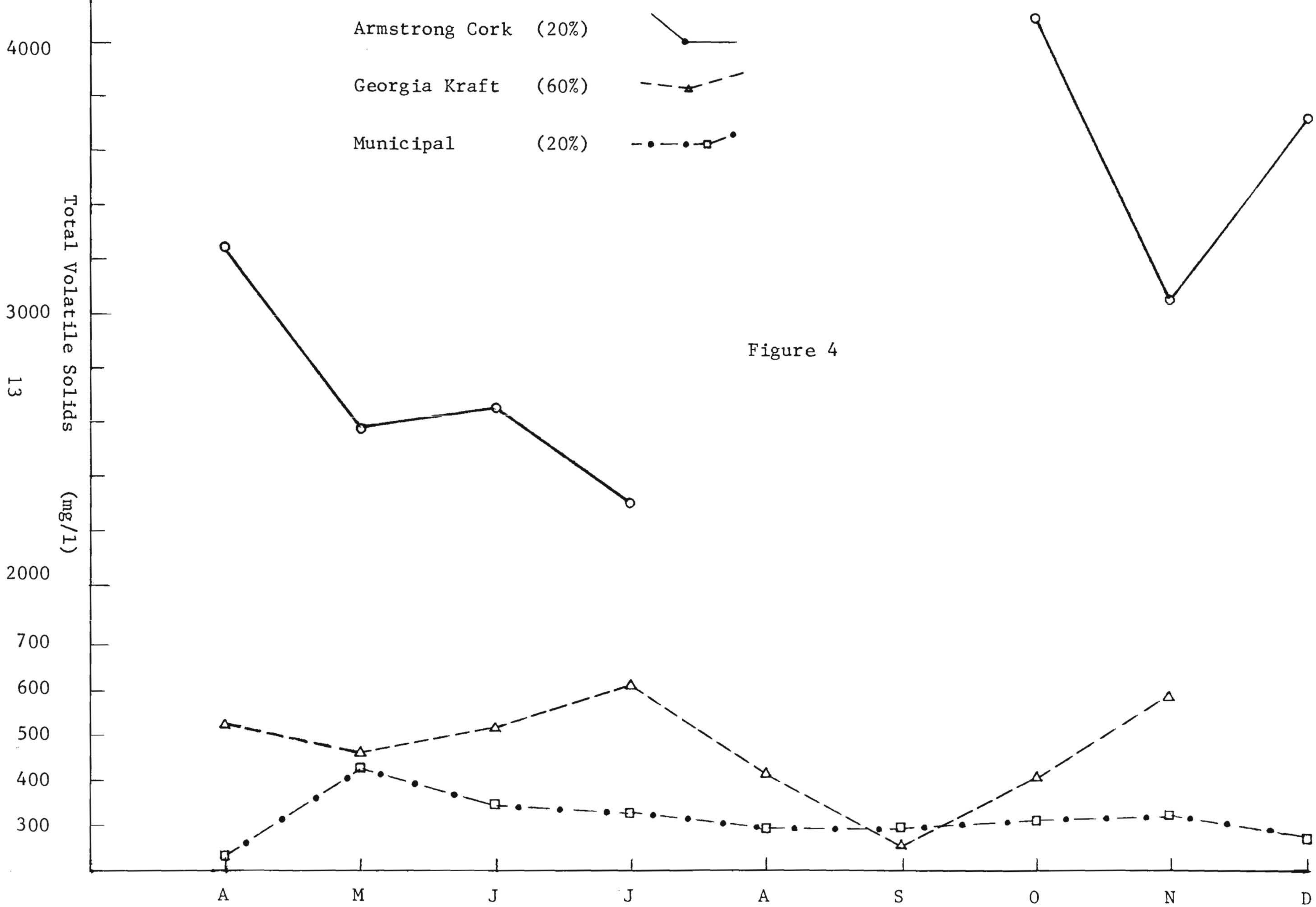


Figure 4

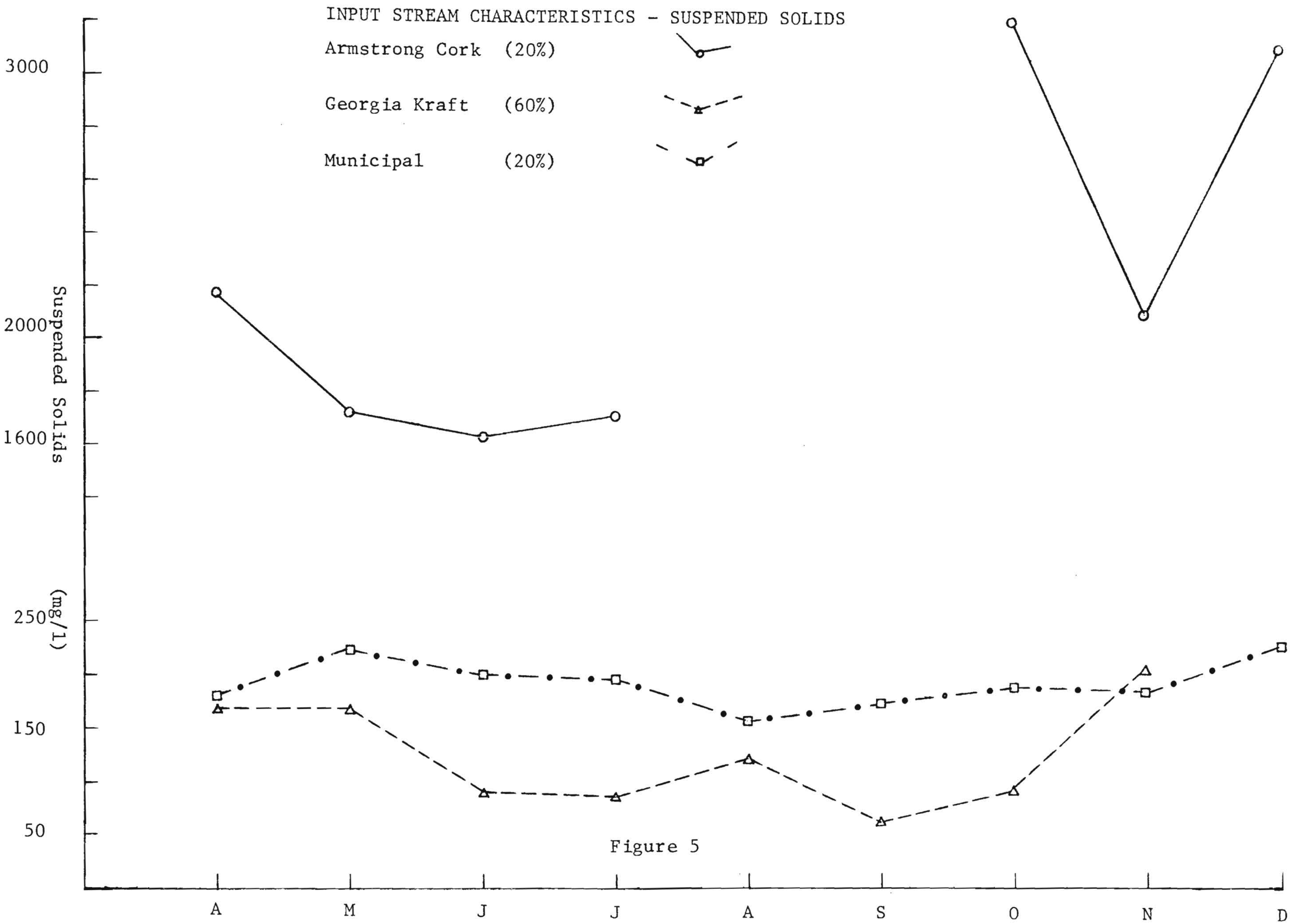

INPUT STREAM CHARACTERISTICS - SUSPENDED SOLIDS
Armstrong Cork (20%)
Georgia Kraft (60%)
Municipal (20%)
3000
2000
1600
250
150
50
Suspended Solids (mg/l)
A
M
J
J
A
S
O
N
D

Figure 5

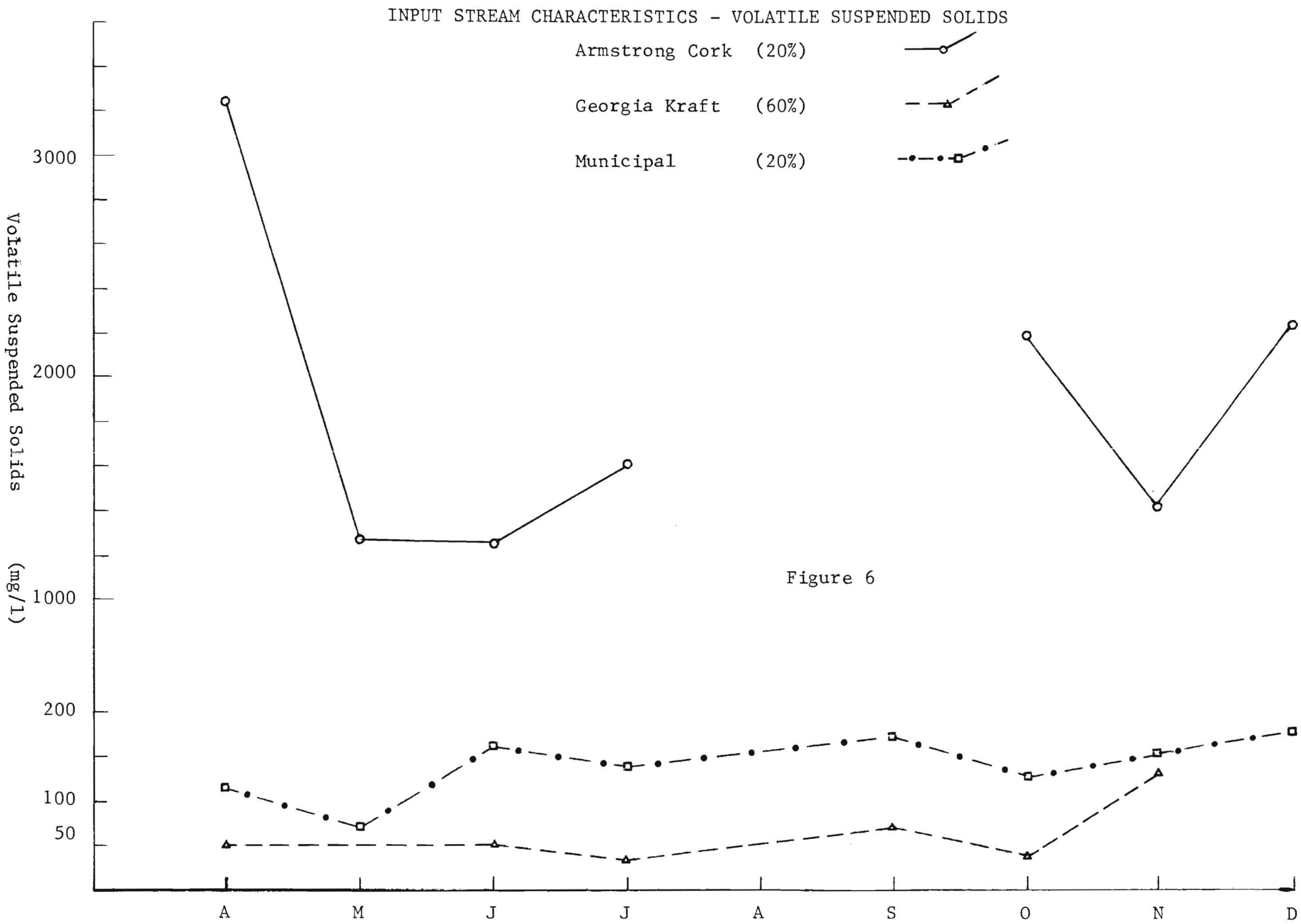

INPUT STREAM CHARACTERISTICS - VOLATILE SUSPENDED SOLIDS
Armstrong Cork (20%)
Georgia Kraft (60%)
Municipal (20%)
Volatile Suspended Solids (mg/l)
3000
2000
1000
200
100
50
A
M
J
J
A
S
O
N
D

Figure 6

INPUT STREAM CHARACTERISTICS - SETTLEABLE SOLIDS

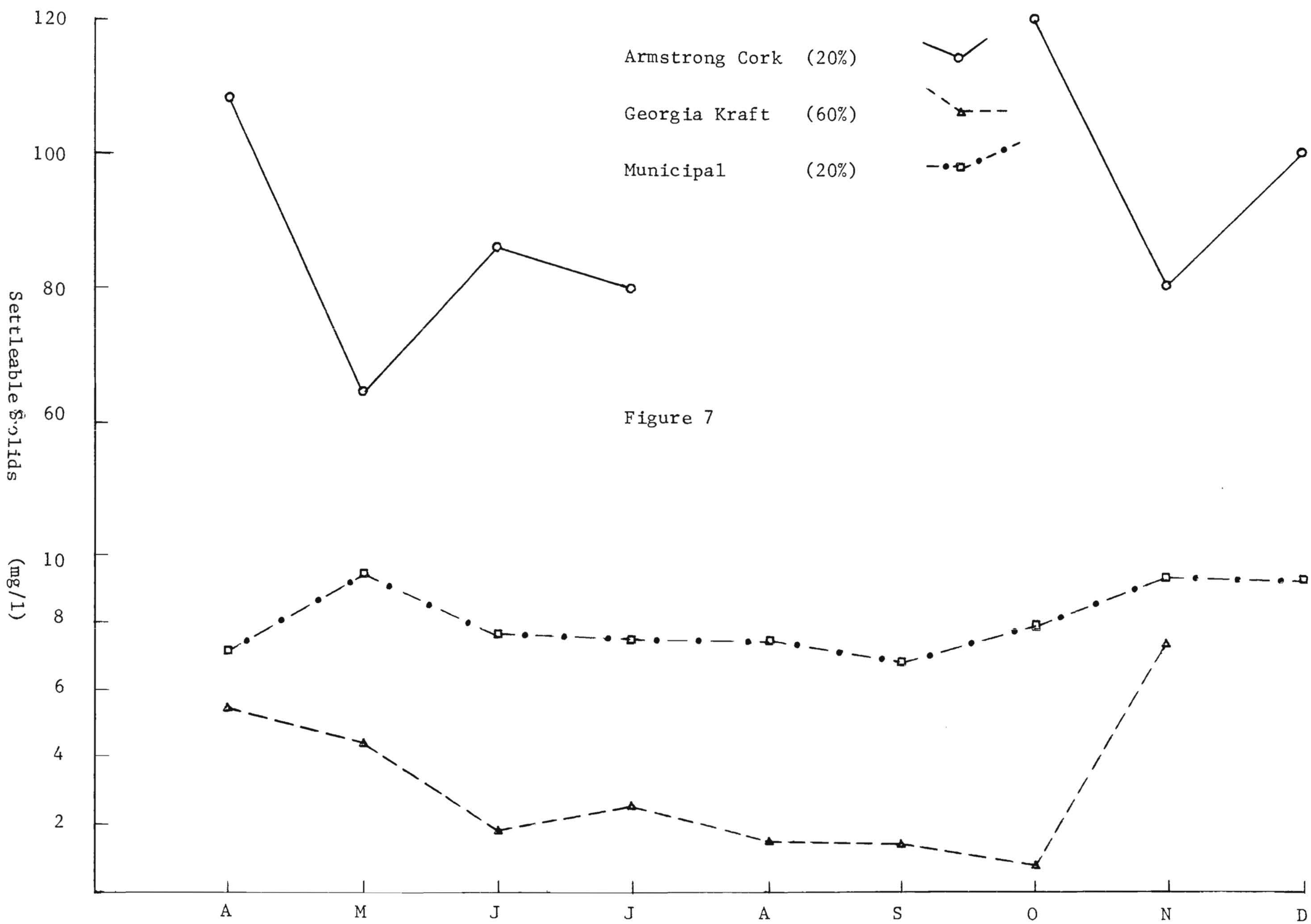


Figure 7

INPUT STREAM CHARACTERISTICS - BOD

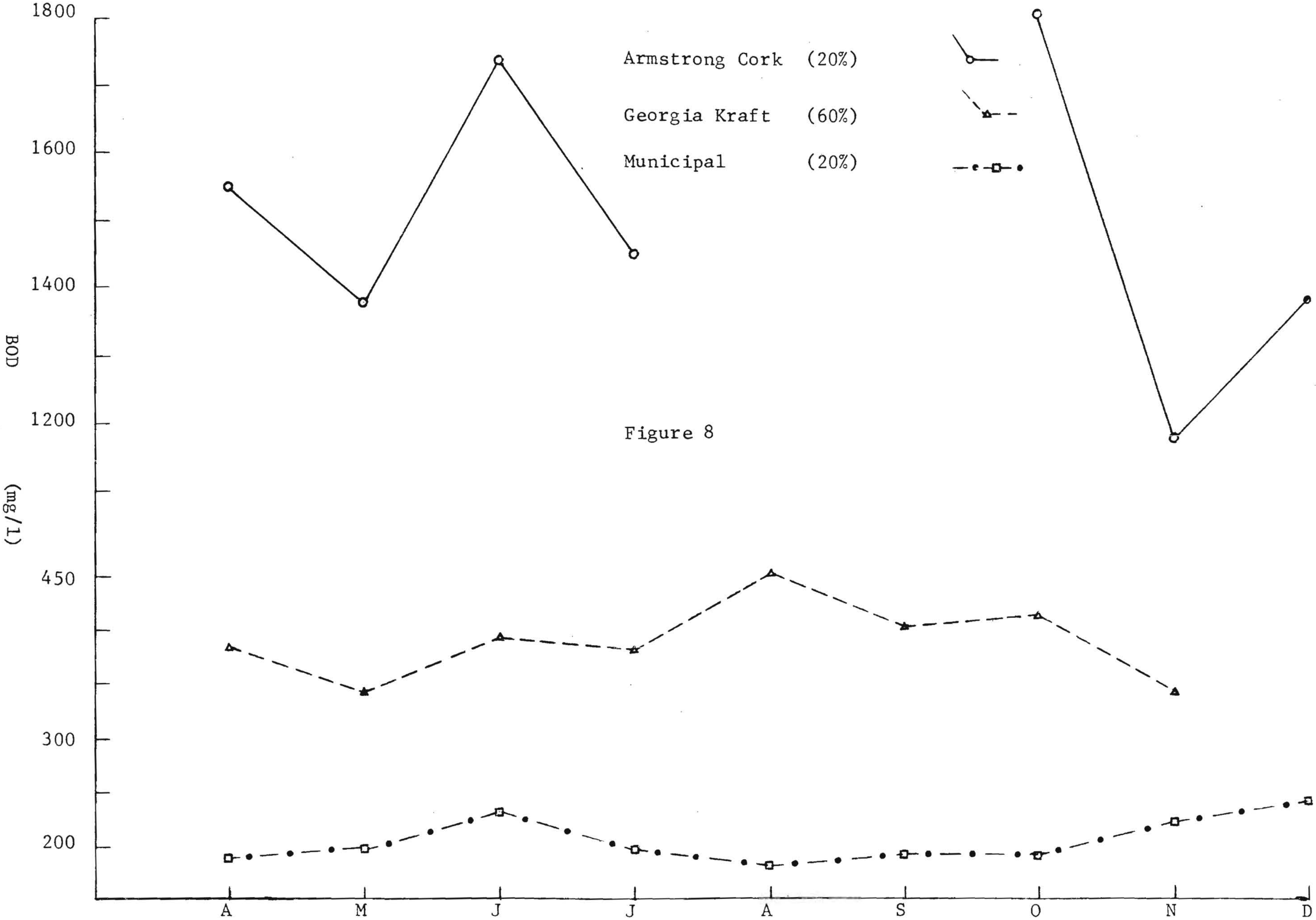


Figure 8

INPUT STREAM CHARACTERISTICS - COD

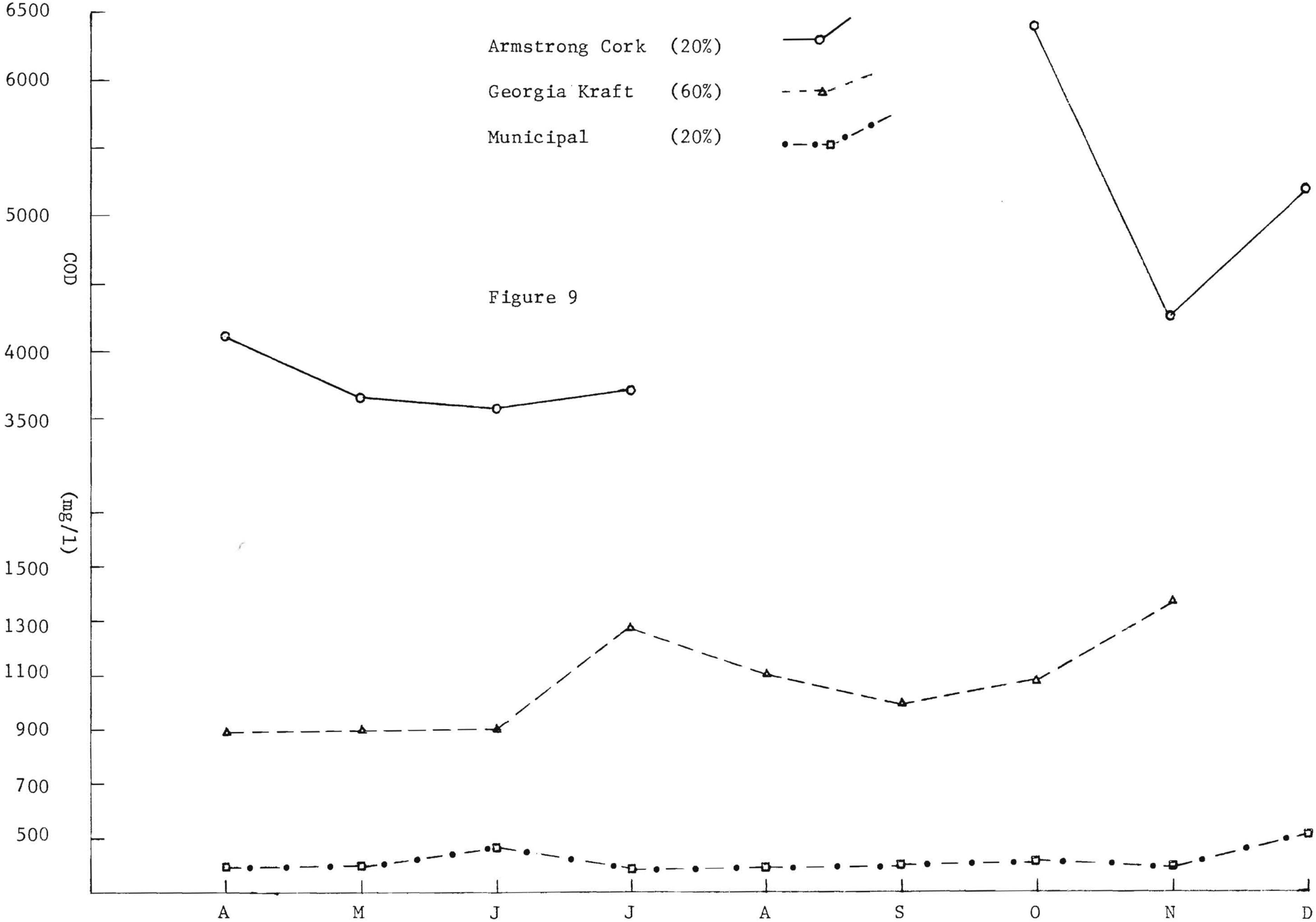
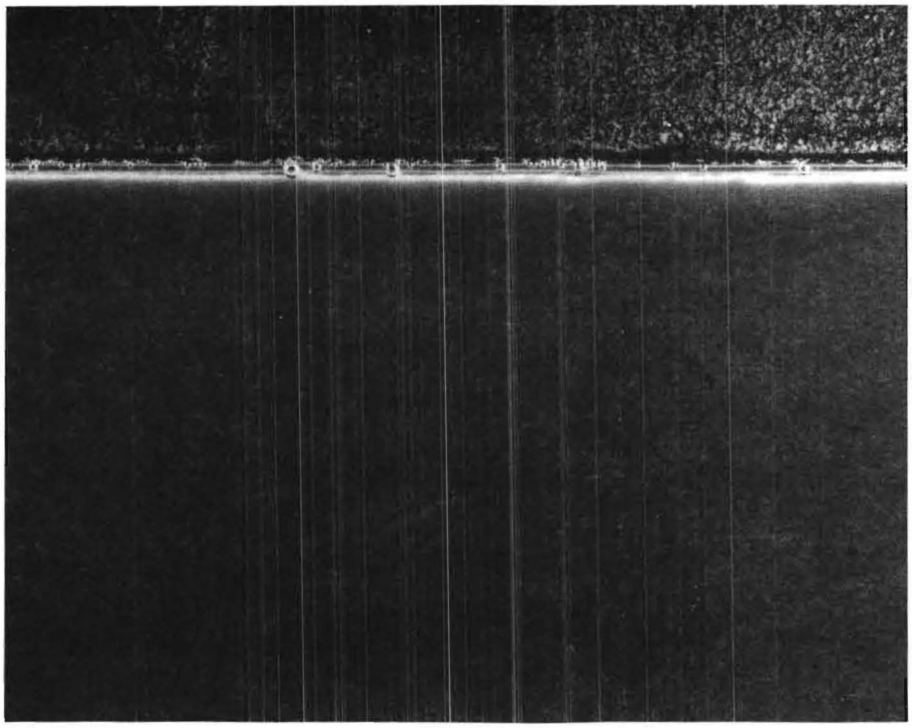


Figure 9

wastes have been put into practice. In the meanwhile, the municipal contribution to the waste stream has increased considerably so that the plant is now operating beyond its designed capacity. As a result of this activity, the compaction phenomenon has become somewhat less striking although it has not disappeared entirely. The results of a more recent test of activity are shown in Figure 10. These changes in the input stream characteristics provided an extra degree of variability which made the interpretation of results more difficult. Since the compaction did continue after the withdrawal of the Armstrong Cork inputs and is not readily observed with municipal wastewaters, the principal investigators feel justified in associating the compaction phenomenon with the pulp mill wastes. Subsequent sections will describe some of the experiments performed in an effort to demonstrate the general applicability of the infrared sludge compaction phenomenon, to characterize the phenomenon, particularly as it relates to the pulp mill component.



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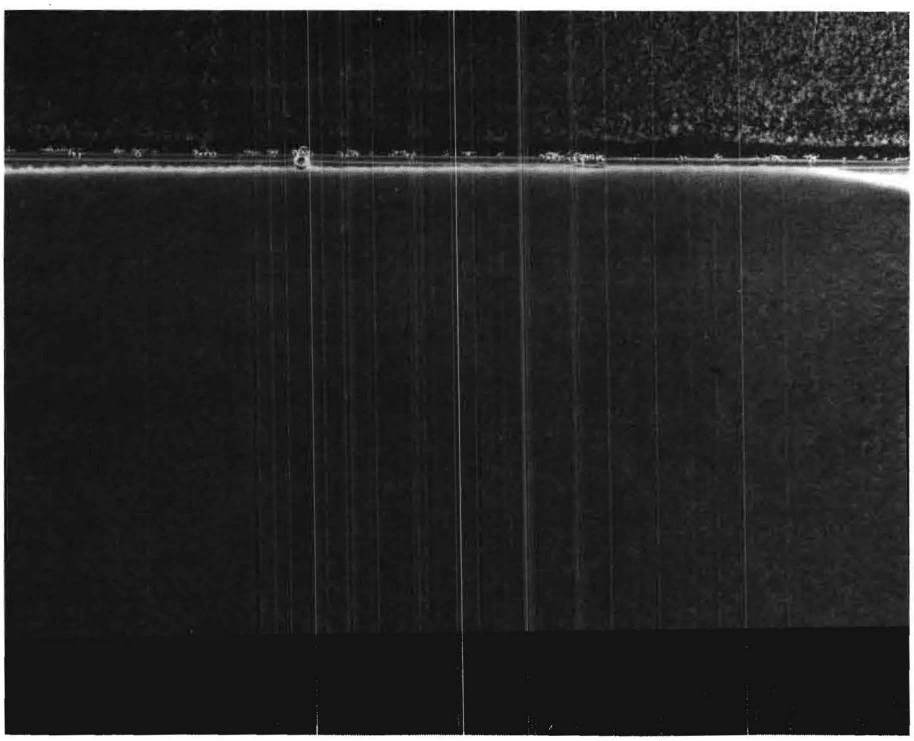
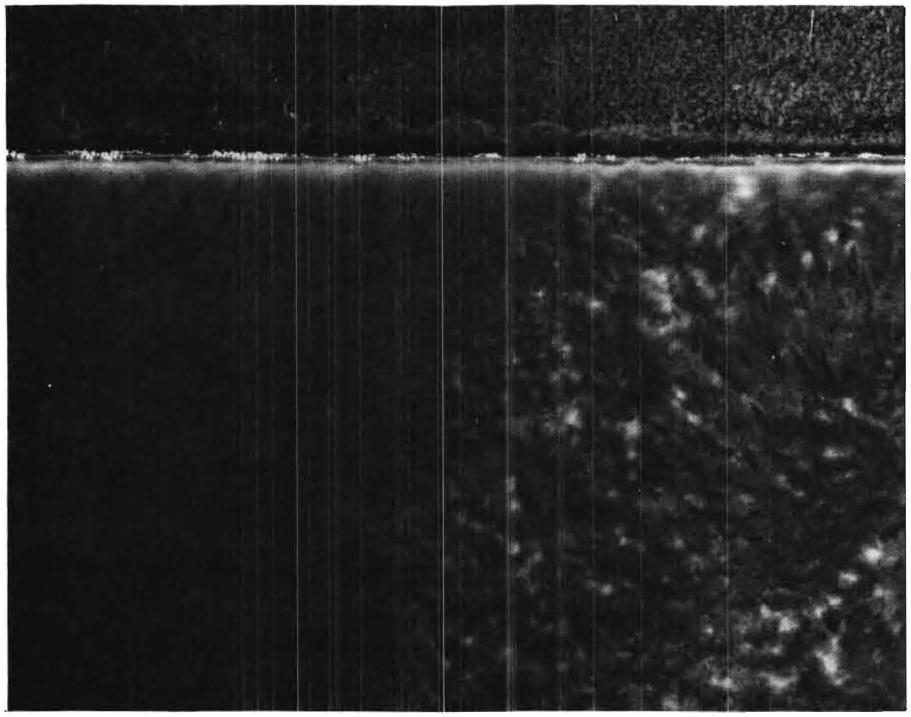
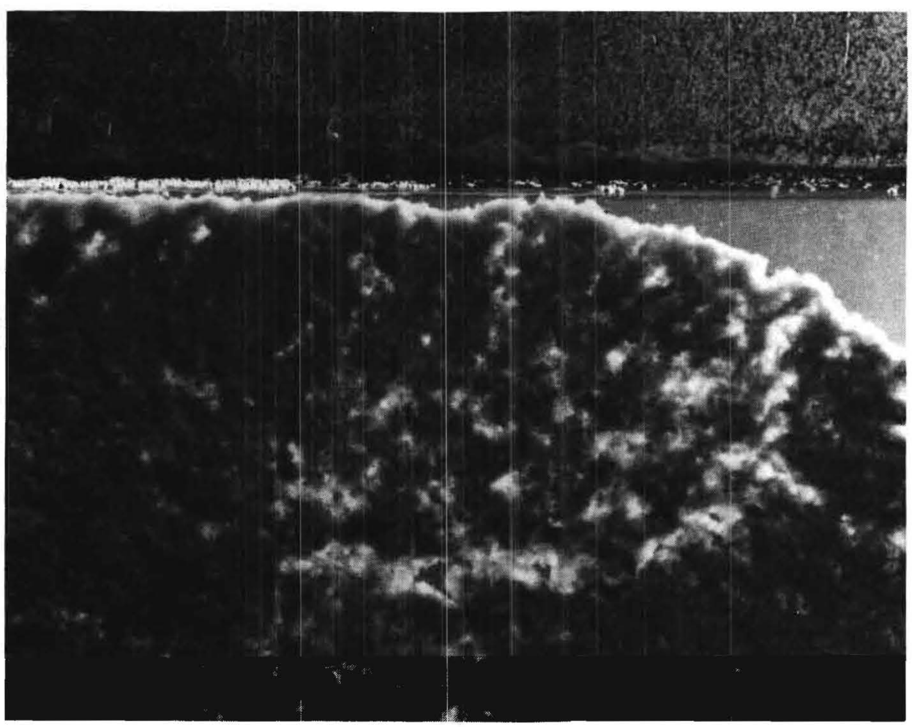


2 minutes

Figure 10a. IR-Induced Settling as a Function of Time

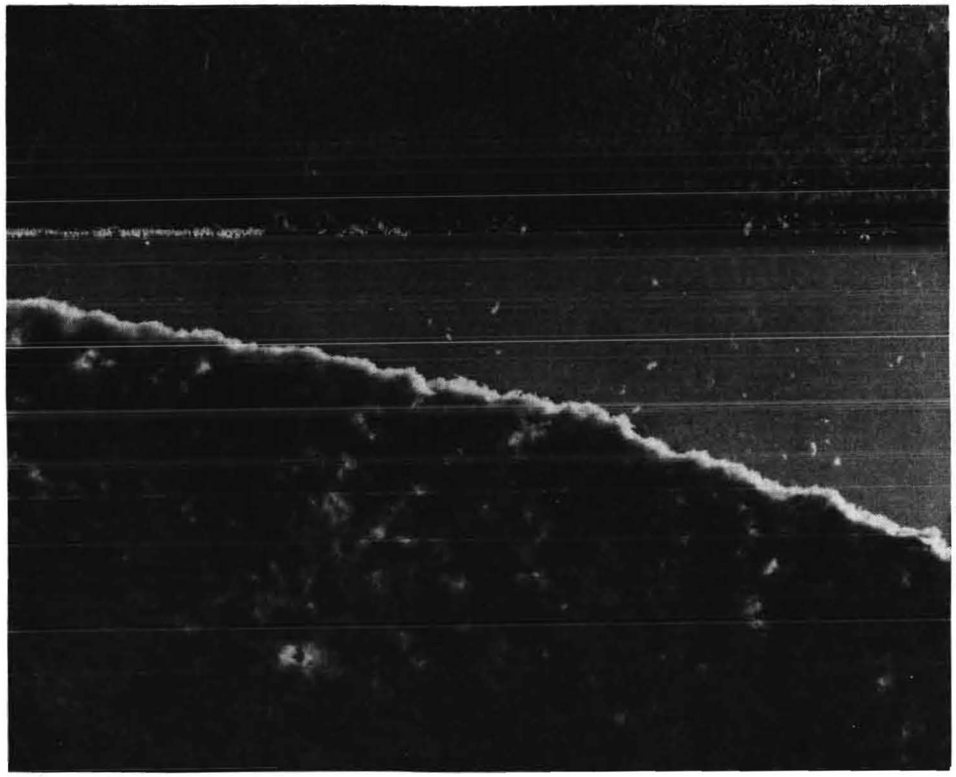


4 minutes



6 minutes

Figure 10b. IR-Induced Settling as a Function of Time



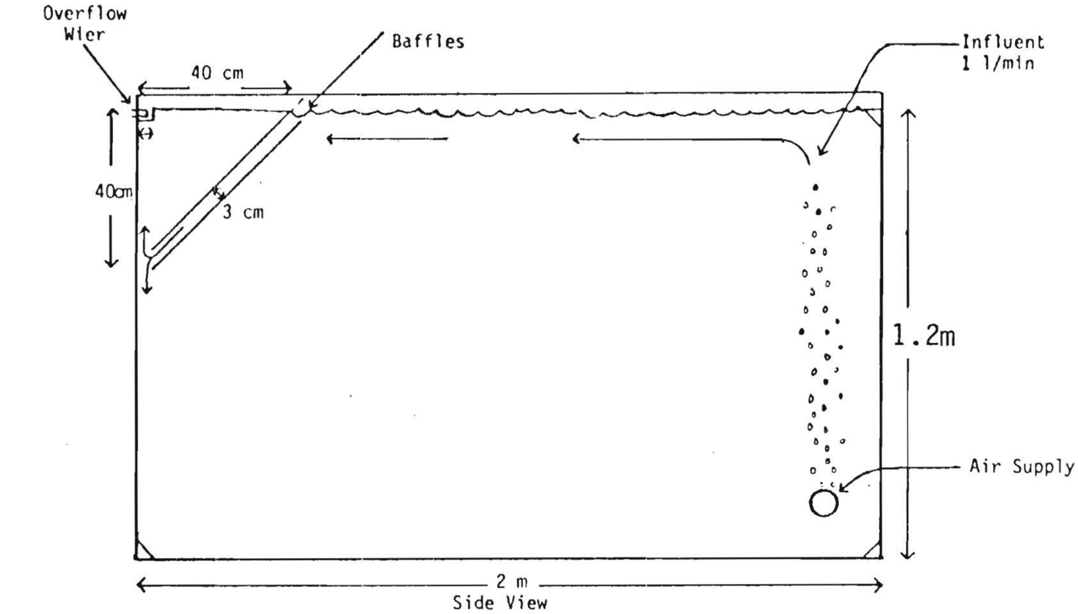
8 minutes

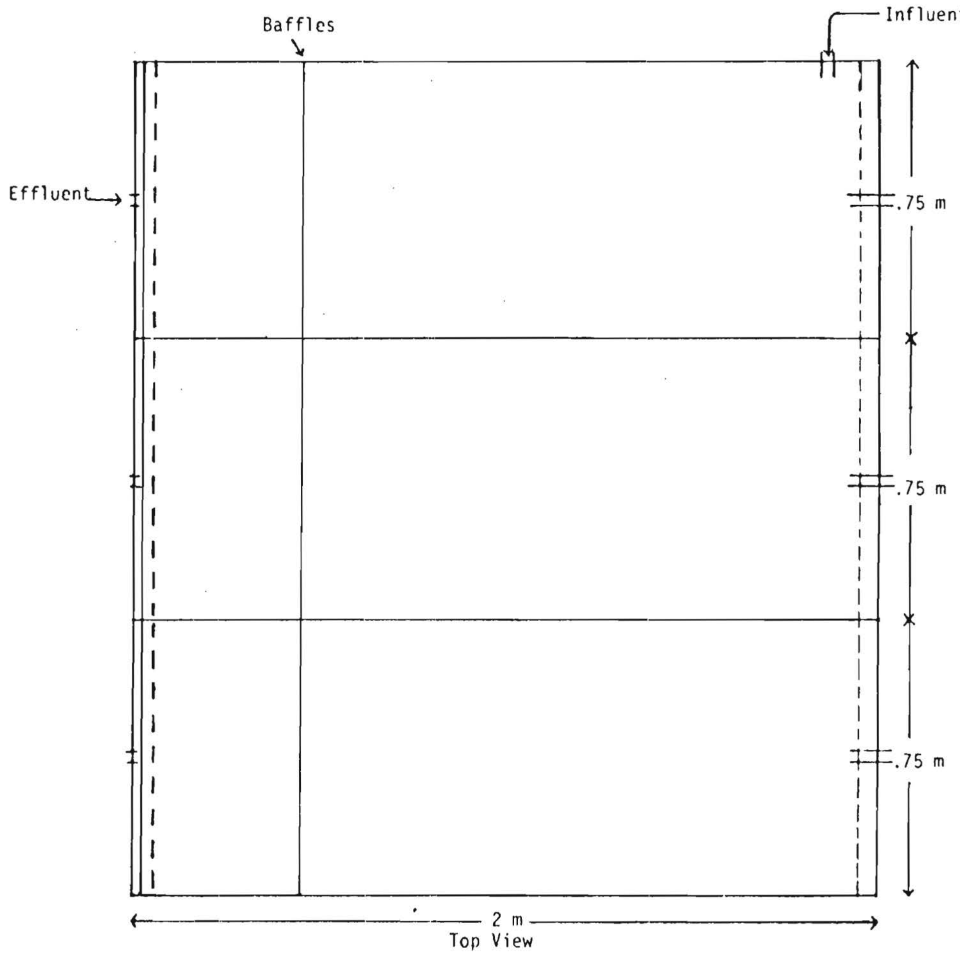
Figure 1 0c. IR-Induced Settling as a Function of Time

CONSTRUCTION AND OPERATION OF THE MINI-PILOT FACILITY

A three-compartment pilot facility was constructed at Georgia Tech immediately following the award of the contract. The design of this apparatus is shown in Figure 11 and is essentially as outlined in our original proposal. The volume of each compartment was about 1.6 m^3. The general rate of feeding was about 1 l/min. The pulp-mill wastewater stream and the domestic wastewater stream were mixed in varying proportions in an effort to determine the minimum pulp-mill contribution required to have the sludge respond to irradiation. These experiments were confused somewhat by irregularities in the composition of the pulp-mill waste stream as the test period coincided with the institution of new water recycling procedures within the pulp-mill itself. Thus the results were somewhat inconclusive.

Figure 11 Mini-Pilot Facility





DESIGN OF IRRADIATION EXPERIMENTS

Early experiments were conducted using a commercial infrared lamp placed approximately 50 cm away from a 500 or 100 ml graduated cylinder containing freshly agitated sludge. A control cylinder was agitated and allowed to stand in a dark corner for the same length of time. Some of the more recent experiments have employed a 100 ml graduated cylinder placed on a phonograph turntable a specified distance from the light source. In this way unequal convection currents would not be set up along the side of the cylinder nearest the lamp. It was first believed that this precaution would only be important for cases in which the test cylinders were so close to the lamp (within 20 cm) that significant heating would occur. Actual temperature readings are now recorded even when the cylinders are 1.0 or 1.5 meters away from the light source as we have become more aware that heating effects are playing a major role in the compaction phenomenon as it is now being observed in the laboratory.

SETTLING PROFILES

Prior to becoming aware of the possible significance of heat alone as a contributor to the compaction phenomenon, the authors had run a number of experiments designed to obtain a profile of the IR-induced settling phenomenon as compared with settling in the absence of irradiation. A graphical representation of some typical results is presented in Figure 12. Each point on the two uppermost traces is the average from at least three separate runs. It is the recollection of Dr. Ingols that the pre-award curves were more like the lowest trace in the Figure.

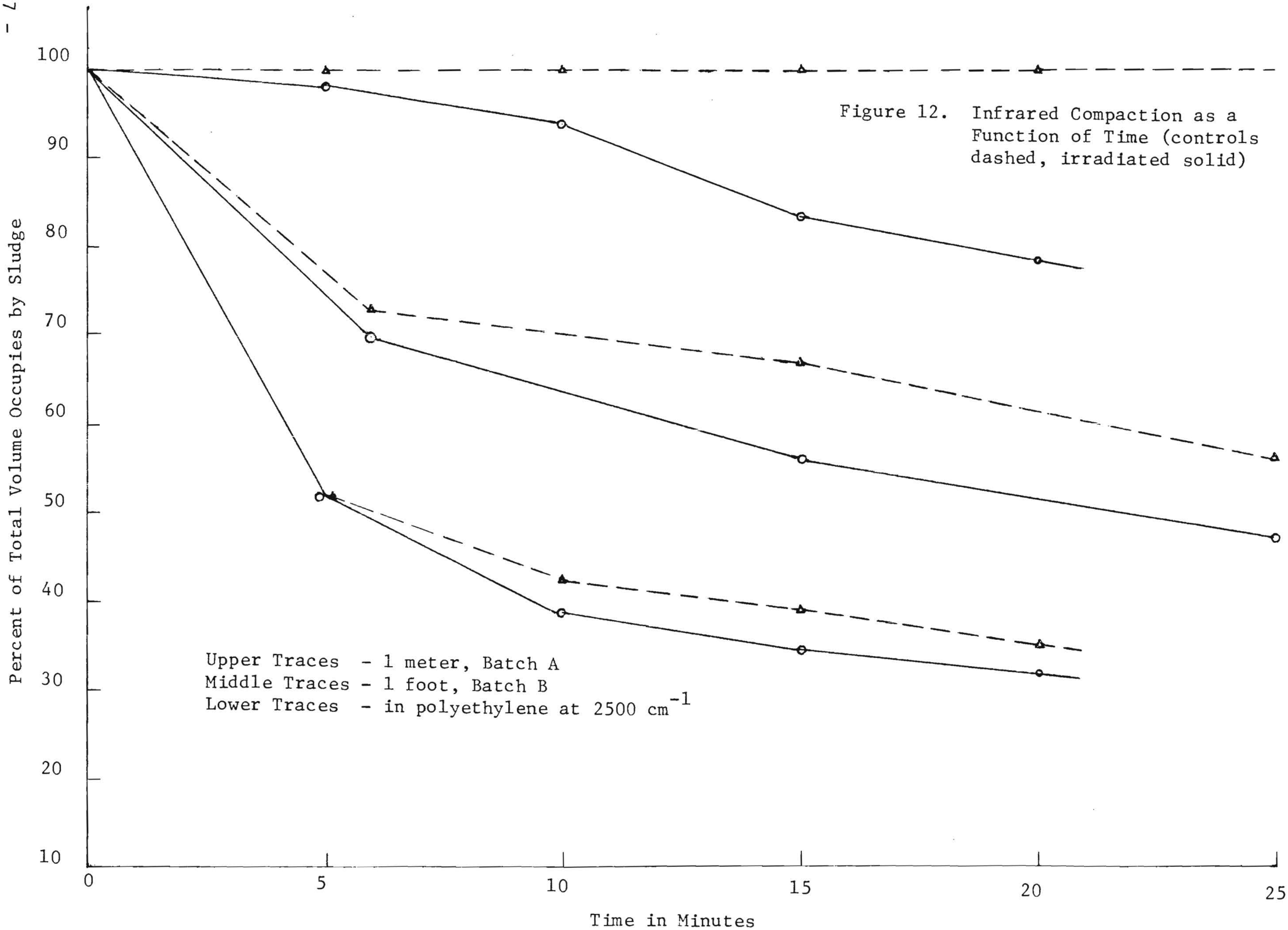


Figure 12. Infrared Compaction as a Function of Time (controls dashed, irradiated solid)

BENCH STUDY - FILTERABILITY

This experiment was designed to determine whether or not differences in the filtration rates could be observed between irradiated sludge and sludge which had not been exposed to infrared radiation. A Buchner funnel was mounted on a filter flask which was, in turn, connected to a constant vacuum source. A disc of Watman No. 1 filter paper was moistened and placed in the funnel for each test. Precision was established by observing the time required to filter 450 ml of tap water. These results are outlined below.

Run	Time in Sec.
1	40
2	40
3	47
4	39
5	50
6	48
7	47
Mean	44.4
Standard Deviation	4.6
% Standard Deviation	±10

This degree of reproducibility was considered to be acceptable. Accordingly 450 ml portions of sludge were filtered. The times required to bring the visible film of water away from all but the outer ring of the filter cakes were recorded for both control and irradiated sludge as outlined on the next page.

Run	Control	Irradiated
1	13.2	17.2
2	14.2	13.2
3	12.5	11.5
4		17.5
Mean	13.3	14.9
Standard Deviation	0.85	3.0
% Standard Deviation	±6.4	±20.0

t = 0.89 for 5 degrees of freedom

Because the two means were not significantly different and because the temperatures of the irradiated sludges had not been controlled, a more rigorous experiment was devised in which the effects of both temperature and irradiation were considered. Measurements were made on the same day using the same batch of sludge (Macon, GA). A factorial design was employed with two levels in each factor being considered as shown below along with the times required for filtration in minutes.

	22° C.		38° C.	
	Lamp On	Lamp Off	Lamp On	Lamp Off
	4.75	4.37	4.0	5.5
	6.15	6.0	4.5	3.68
	5.5	5.17	4.0	5.2
	5.25	4.7	4.82	4.0
	5.17	4.87		
Means	5.36	5.02	4.33	4.59

These results were subjected to statistical analysis on Georgia Tech's CYBER 74 time-shared computer system using the SPSS ANOVA n-way

analysis of variance program. The results of this statistical treatment of the data, which are presented below show that no statistically significant effect of the irradiation alone was observed. On the other hand, a significant temperature effect (p = 0.027) was noted. The two-way interaction was not significant. The temperature effect is to be expected on theoretical grounds and therefore supports the overall validity of the experiment.

\- - - ANOVA - - -

TIME
BY LAMP
TEMP

SOURCE OF VARIATION	SUM OF SQUARES	DF	MEAN SQUARE	F	SIGNIF OF F
MAIN EFFECTS	2.395	2	1.198	3.Ø72	.Ø78
LAMP	.Ø23	1	.Ø23	.Ø6Ø	.81Ø
TEMP	2.372	1	2.372	6.Ø84	.Ø27
2-WAY INTERACTIONS	.4Ø9	1	.4Ø9	1.Ø5Ø	.323
LAMP TEMP	.4Ø9	1	.4Ø9	1.Ø5Ø	.323
EXPLAINED	2.8Ø5	3	.935	2.398	.112
RESIDUAL	5.457	14	.39Ø		
TOTAL	8.262	17	.486		

18 CASES
Ø MISSING (Ø PCT)

The t-test data which are presented below include the means, standard deviations and standard errors for each of the cells. These results also support the conclusion that irradiation produced no significant changes while the elevated temperature produced a significant improvement in the filtration rate.

- - - T - TEST - - -

TIME

	GROUP 1 Lamp On	GROUP 2 Lamp Off
NO. OF CASES	9	9
MEAN	4.2044	4.3322
STD. DEV.	.7006	.7341
STD. ERROR	.2335	.2447
F-VALUE	1.10	
2-TAIL PROB.	.898	

	T-VALUE	DF	P-VALUE
POOLED VAR. EST.	.21	16	.834
SEPARATE VAR. EST.	.21	15.97	.834

- - - T - TEST - - -

TIME

	GROUP 1 22°C	GROUP 2 38°C
NO. OF CASES	10	8
MEAN	5.1930	4.4625
STD. DEV.	.5663	.6550
STD. ERROR	.1791	.2316
F-VALUE	1.34	
2-TAIL PROB.	.669	

	T-VALUE	DF	P-VALUE
POOLED VAR. EST.	2.54	16	.022
SEPARATE VAR. EST.	2.50	13.99	.026

SETTLING VS. WAVELENGTH

Preliminary tests designed to uncover a dependency of the compaction phenomenon upon the wavelength of the incident radiation were carried out in quartz UV - vis spectrophotometer cells. Unfortunately, these cells were transparent (80% T or better) only from 2800-3400 cm^{-1}. Some light was able to pass through the cells from 2100-3800 cm^{-1} (10% T or better), albeit with varying intensity. For this reason, nearly all of the observations made with this equipment must be regarded as inconclusive. The results described in our letter of April 19, 1978 are worthy of note, however, since the ratios of control to irradiated samples were found to be 1.3 at 2100 cm^{-1} and 2200 cm^{-1} and nearly unity at 2300, 2400 and 2700 cm^{-1} in spite of the fact that the cells are more transparent to infrared radiation at the less responsive wavelengths. Unfortunately, this difference, although still observed in subsequent repeated experiments was not nearly as dramatic and, in fact, was no longer sufficiently large to be considered statistically significant.

In an effort to overcome this difficulty, new cells were constructed first out of polystyrene and finally out of polyethylene. While both were found to have vastly improved transmission properties when compared to those exhibited by the quartz cells, the polyethylene showed only three narrow adsorption bands at 2900-3150, 1480-1530 and 760-780 cm^{-1} and was essentially transparent throughout the rest of the range of the spectrophotometer. Since polystyrene had a number of other bands in addition to these three, all subsequent work has been carried out with the polyethylene.

While experiments in this area did not reach any strong conclusions it was apparent that irradiation for 15-20 minutes shows an effect at 2200 and 2300 cm^{-1} but not at 2500 cm^{-1}. The observed ratios of control to irradiated samples were 1.2, 1.1 and 1.0 respectively. This evidence agrees with that reported earlier. Temperatures were not recorded. In order to more conclusively resolve this issue, a more intensive variable wavelength light source would be required. The investigators did not believe that the procurement of such a source would produce sufficient information to justify the investment.

MEMORY EFFECT

If the infrared-induced compaction involves a redistribution of surface charges as has been speculated in earlier reports, it would seem unlikely that such an effect would be totally reversible. While early results had indicated that a very high degree of reversibility was characteristic of the phenomenon, a quantitative assessment of this observation was not undertaken until the current reporting period. A sample of sludge from the Macon facility was placed in a 100 ml graduate and subjected to infrared radiation in the usual manner. After 10 minutes of irradiation, the ratio of percent settling in the control to that of the irradiated sample was 2.9. The two samples were then resuspended and allowed to resettle. The ratio recorded after 4 minutes was 1.4 thus demonstrating that the effect is only partly reversible.

EFFECT OF pH, SALT, DETERGENT AND SOLVENT EXTRACTION

Changing the pH to 4 and 9 did not alter the degree of response to infrared radiation. Adding a sufficient amount of sodium chloride to make the resulting mixture 1% in NaCl did not alter the IR response, although the change in density was sufficient to cause the IR-compacted sludge to float instead of sink.

Adding a very large amount of anionic detergent (enough to make the final solution 1%) changed the appearance of the IR-induced compaction in that the agglommerating floc particles seemed larger and smoother but did not appear to change their rate of settling. Hexane and ethyl acetate extractions introduced complicating factors in that solvent residuals subsequently caused the compacting sludge to float. Nevertheless it was possible to conclude that the IR activity was not being extracted away.

EFFECT OF LIGNOSULFONATE AND ADDED POLYELECTROLYTES ON ORDINARY ACTIVATED SLUDGE

This section describes the series of experiments outlined in Item 3 of our letter of March 16, 1978. The experimental design is presented below.

- Sludge With No Added Lignosulfonate
  - No Chemical Addition
  - Addition of Polyelectrolyte
- Sludge With Added Lignosulfonate
  - No Chemical Addition
  - Addition of Polyelectrolyte

As described briefly in our letter of July 10, 1978, this experiment produced some very interesting results in that the untreated samples showed a strong response to the infrared radiation. Furthermore, the results of polyelectrolyte addition were much more dramatic than had been anticipated. It will be noted that a cationic, non-quaternary polyelectrolyte (Purifloc C-31, Dow) was used in place of the Chitosan. This substitution was made on the basis of solubility considerations. In retrospect, Chitosan would probably have performed as well.

The compositions of the test mixtures are summarized below:

1) No chemical addition, Bolton Sludge, 2 liters
2) No. 1 plus 15 ml of a 1% solution of Purifloc C-31
3) No. 1 plus 40 ml of 1% lignosulfonate solution
4) No. 1 plus 15 ml of Purifloc plus 40 ml lignosulfonate

The mixtures were aerated and fed irregularly with 25 ml of a solution containing 24 g dextrose, 5.0 g glycine and 800 mg disodium hydrogen phosphate per liter. The type of food and feeding schedule were designed to encourage bulking. The addition of reagents was begun as

soon as bulking began to develop. Feeding was done in such a manner as to minimize salt buildup. Irradiations were conducted for 15 minutes in 10 ml graduates at a distance of 50 cm. The experimental results which are reported as $\frac{\text{volume of control sludge}}{\text{volume of IR compacted sludge}}$ are presented below in Table 2.

Table 2

Effect of Lignosulfonate and Polyelectrolyte on IR-Compaction

	Time	Run 1	Run 2	Run 3	Run 4	Run 5
No Additions	Initial	2.12	1.65	1.76	1.81	1.61
Added Polyelectrolyte*	Initial	2.0	1.0			
Added Lignosulfonate	Initial	1.45	1.47	1.54	1.63	
Added Polyelectrolyte Plus Lignosulfonate*	Initial	1.8	1.0			
No Additions	12 hrs.	1.49	1.34	1.59		
Added Polyelectrolyte*	12 hrs.	0.8				
Added Lignosulfonate	12 hrs.	1.53	1.18	1.47		
Added Polyelectrolyte Plus Lignosulfonate*	12 hrs.	1.4				
No Additives	24 hrs.	1.01	1.02	1.03	1.03	
Added Polyelectrolyte*	24 hrs.	1.0				
Added Lignosulfonate	24 hrs.	1.02	1.07	1.06	1.03	
Added Polyelectrolyte Plus Lignosulfonate*	24 hrs.	0.8				

* The presence of polyelectrolyte compacted the sludge to 5-10% of the original volume thus making comparative measurements difficult to obtain.

Visual inspection indicated the heavy involvement of filamentous organisms after 24 hours, thus making the last series of observations somewhat questionable. The added lignosulfonate increased the degree of bulking about 10% and may have decreased the measured ratios somewhat. A statistical analysis was performed on the data in an effort to resolve these and other questions. Georgia Tech's CYBER 74 multiprocessor computer system was used in combination with the SPSS software to perform an analysis of variance and t-tests on the data presented in Table 2 . The results of this work are presented below.

```
- - - ANOVA - - -

            RATIO
         BY POLY
            LIGNO
            TIME
```

SOURCE OF VARIATION	SUM OF SQUARES	DF	MEAN SQUARE	F	SIGNIF OF F
MAIN EFFECTS	2.350	4	.588	10.095	.001
POLY	.294	1	.294	5.060	.037
LIGNO	.042	1	.042	.719	.407
TIME	2.128	2	1.064	18.283	.001
2-WAY INTERACTION	.210	5	.042	.723	.615
POLY LIGNO	.054	1	.054	.930	.347
POLY TIME	.032	2	.016	.272	.764
LIGNO TIME	.138	2	.069	1.184	.328
3-WAY INTERACTION	.158	2	.079	1.361	.280
POLY LIGNO TIME	.158	2	.079	1.361	.280
EXPLAINED	2.719	11	.247	4.247	.003
RESIDUAL	1.106	19	.058		
TOTAL	3.825	30	.127		

31 CASES
0 MISSING (0 PCT)

The interpretation of the above results is that the effect of added POLYelectrolyte is significant (0.037). The true significance is probably greater than shown on account of the fact that the degree of settling produced by the polyelectrolyte was tenfold greater than that which was observed in its absence. Thus when these samples were subjected to infrared light it was very difficult to establish ratios. It is probably more accurate to say that the polyelectrolyte produced dramatic changes in the settling characteristics of the sludge, regardless of whether or not it was subsequently exposed to infrared light. The influence of the added LIGNOsulfonate on the compaction ratios is not highly significant (0.407). In this case, the ease of measurement and number of comparisons are in better balance so that it is safe to say that the sludge responded to the infrared light in about the same way whether or not the lignosulfonate was present. Time was the most significant factor (0.001). Thus it is virtually certain that the length of time which the bulking has existed has the strongest influence on whether or not the sludge will respond to infrared light. This is probably related to the physical/chemical properties of the sludge and may explain why not all sludges respond equally to IR light. The T-test shown on the next page is supportive of the ANOVA conclusion regarding the effect of the polyelectrolyte. However, it is not significant in itself. The means and standard deviations are presented as a part of this data.

The next T-test examined the effect of lignosulfonate on the compaction ratios and like the ANOVA data was not statistically significant. The printout is presented on the next page.

--- T - TEST ---

RATIO

	GROUP 1 NO POLY	GROUP 2 WITH POLY
NO.OF CASES	23	8
MEAN	1.3874	1.2250
STD. DEV.	.3157	.4590
STD. ERROR	.0658	.1623
F-VALUE	2.11	
2-TAIL PROB.	.170	

	T-VALUE	DF	P-VALUE
POOLED VAR. EST.	1.11	29	.275
SEPARATE VAR. EST.	.93	9.41	.378

--- T - TEST ---

RATIO

	GROUP 1 NO LIGNO	GROUP 2 WITH LIGNO
NO.OF CASES	16	15
MEAN	1.3912	1.2967
STD. DEV.	.4147	.2898
STD. ERROR	.1037	.0748
F-VALUE	2.05	
2-TAIL PROB.	.188	

	T-VALUE	DF	P-VALUE
POOLED VAR. EST.	.73	29	.470
SEPARATE VAR. EST.	.74	26.88	.466

The last T-test compared time period 1 (initial) with time period 3 (24 hours). The results showed that time is a very significant factor in determining the degree of response to irradiation. These results are summarized below.

- - - T - TEST - - -

RATIO

	GROUP 1 INITIAL		GROUP 2 24 HOURS
NO.OF CASES	13		10
MEAN	1.6031		1.0070
STD. DEV.	.3300		.0757
STD. ERROR	.0915		.0239
F-VALUE	18.99		
2-TAIL PROB.	.000		

	T-VALUE	DF	P-VALUE
POOLED VAR. EST.	5.57	21	.000
SEPARATE VAR. EST.	6.30	13.61	.000

TOC measurements were made on the initial supernatants. The results of these tests indicated that the untreated supernatant was the lowest and the lignosulfonate-treated the highest in TOC. The higher levels of TOC in the polymer-treated supernatants probably represent unreacted polymer since larger-than-usual amounts were added. The fact that the doubly treated supernatant showed a TOC which was lower than that observed with lignosulfonate alone indicates that the anionic (lignosulfonate) and cationic (Purifloc C-31) polymers are removing each other from solution. This conclusion is supported by the observation that this supernatant lacks the brown lignosulfonate color.

Mr. Poythress reports attempting to use polyelectrolytes to enhance settling characteristics both on the bench and in the Rocky Creek facility itself. Cationics are effective 90% of the time and when they don't work, anionics do. The sludges remained biologically effective. In-plant use was not successful however, due largely to mixing problems.

INDUCTION OF THE COMPACTION PHENOMENON IN ORDINARY ACTIVATED SLUDGES

In an effort to establish the general occurrence and hence the general utility of the phenomenon, activated wastewater sludges from Atlanta's Bolton, Utoy Creek, Clayton, Flint River and South River wastewater treatment facilities were brought to the laboratory and dosed with a carbohydrate-rich synthetic food mixture in order to induce bulking. No other chemical additions were made in this series of experiments. After periods of time ranging from 1 to 3 days, bulking was observed in all but the South River samples. Filamentous organisms did not appear to be dominant when bulking first occurred, but their numbers increased as the experiments continued. The response ratio was measured by comparing the volumes occupied by unsettled sludge in 10 ml graduated cylinders placed 50 cm from the infrared source and irradiated for 15 minutes with the volumes of unsettled sludge in 10 ml graduates which had not been exposed to the light. The results of these tests are summarized in Table 3. These results were quite exciting at the time and seemed to indicate that the phenomenon was not an isolated occurrence and was, in fact, rather common. The authors' natural conservatism, however, suggested taking a temperature profile of the sludges as they responded to the radiation. This work is described in the next section.

Table 3

Induction of IR-Compaction in Wastewater Sludges*

Source	1st Run	2nd Run	3rd Run	4th Run
Bolton	1.47	1.71	1.49	
Utoy Creek	1.47	1.37	1.31	
Clayton	0.99	1.00		
Flint River	1.12	1.10	1.13	
South River	Near 1.00	-	-	
Utoy Creek (later date)	1.37	1.19	1.12	1.40
Concentrate of Above	1.42	1.51	1.54	1.52

*Ratios = $\frac{\text{volume control sludge}}{\text{volume irradiated sludge}}$

EFFECT OF HEAT

In connection with our experiments designed to induce the compaction phenomenon in other bulking sludges, a series of experiments was designed to investigate the effect of heat alone on the compaction of bulking sludges. Since work predating the award of the contract had shown no heat effect, it was most disconcerting to note that the very first attempt to produce a heat-induced compaction which was performed on a sample of IR-active Macon sludge showed a degree and type of compaction which was exactly like that which had been observed with the infrared lamp. The effects were so much alike that it was not possible for an independent observer to distinguish which means had been used to produce the phenomenon. An examination of the behavior of locally obtained sludges into which the bulking phenomenon had been induced when heated to 70^{o}C in a hot water bath produced the results shown in Table 4. All samples were placed in 10 ml graduated cylinders exposed for 15 minutes after which time the volumes occupied by the sludges were compared with those of equal amounts of sludge which had been kept at room temperature for the same length of time. These results expressed as $\frac{\text{volume control sludge}}{\text{volume exposed sludge}}$ confirmed that the effect of this amout of heat was at least equal to the effect of the infrared radiation.

Detailed qualitative observations regarding the rate of temperature climb and the appearance of the sludge (Macon) with time during exposure to heat alone (hot water) and infrared radiation in separate tests again led to the conclusion that no obvious differences could be found between

Table 4

Effect of Heat Upon Compaction of Sewage Sludge

Source	Run 1	Run 2	Run 3
Utoy Creek	3.00	2.78	2.86
Flint River	1.28	1.16	
South River	1.17	1.43	1.33
Clayton	2.91	3.21	2.59
Macon	2.37		

the compactions induced by either mechanism. The final ratios were exactly the same.

In an effort to find at least one differentiating feature, the two compacted sludges were resuspended and allowed to resettle. Much to the experimenter's surprise, the infrared-compacted sludge exhibited the "memory" effect previously observed while the heat-compacted sludge immediately showed a weaker memory effect. This difference persisted throughout the three-hour observation period. The final ratios of control to exposed were 1.93 and 1.70 respectively. These observations suggested that further experimentation might yet succeed in separating the IR effect from the heat effect.

ISOLATING THE EFFECTS OF TEMPERATURE AND INFRARED RADIATION

As soon as the magnitude of the heat-induced compaction began to be appreciated, the authors sought to coneive of an experimental design which could isolate the two effects. A simple plan for maintaining a constant temperature during irradiation involved sheathing the graduated cylinder which was being irradiated in a stream of flowing water. Hopefully a thermal equilibrium would be established at a temperature which was not very different from that of the water itself. Preliminary experiments established that temperatures in the range of 27-30^{o}C (depending on the flow rate of the water) could be maintained using Atlanta tap water.

A series of experiments was set up on the basis of this information in which samples of sludge (50 ml) were irradiated at a distance of 20 cm for 15 minutes while encircled by a sheath of running water which was flowing at such a rate as to maintain the temperature at 28^{o}C. Comparison samples were immersed in a water bath away from the light at 28^{o}C while still other samples were held in the dark at room temperature (22^{o}C). A comparison of the sludge volumes in the 22^{o} controls with those in the irradiated samples provides an estimate of the degree of response due to both heat and light. A similar comparison of the compacted sludge volumes in the control at 28^{o}C and the infrared-exposed samples at 28^{o}C isolates the effect of light. A final comparison between the non-irradiated sludge volumes at 22^{o}C and at 28^{o}C provides a measure of the degree of response due to heat alone. The results of eight replicate tests are presented in Table 5.

Table 5

Effects of Temperature and Infrared Radiation

Run No.	Volume of Control at 22^{o}C / Volume of IR at 28^{o}C	Volume of Control at 28^{o}C / Volume of IR at 28^{o}C	Volume of Control at 22^{o}C / Volume of Control at 28^{o}C
1	1.37	1.36	1.01
2	1.21	1.08	1.12
3	1.27	1.12	1.14
4	1.20	1.13	1.04
5	1.24	1.22	1.02
6	1.43	1.43	1.01
7	1.09	1.07	1.02
8	1.17	1.07	1.09

A statistical analysis of the data was performed using the T-test in order to help answer the following questions:

1. Is the degree of response to heat and infrared light together significantly different from that due to IR alone? A comparison of Columns 1 and 2 provides an estimate. The statistical evidence ($t = 3.02$, $p < 0.01$) indicates that there is a highly significant difference between the response to both factors and the response to IR alone. Thus the effect of heat cannot be ignored.
2. Is the degree of response to both heat and infrared light significantly different from that due to heat alone? In this case a comparison of Columns 1 and 3 provides the estimate ($t = 4.07$, $p < 0.005$). This means that there is a very highly significant difference between the degree of response to both factors and the response to heat alone. Thus the effect of IR cannot be ignored either.